TARGET SIMULATIONS FOR NDCX II*

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Outline:

1. Planar targets: exploiting volumetric ion beam energy deposition

2. Machine tradeoffs: ion energy, pulse energy, and pulse duration

3. WDM experiments:
   - Equation of state

4. IFE relevant experiments:
   - Ion coupling: using ramped ion energy to maximize shock strength
   - Hydrodynamic stability

5. Other target geometries: cylindrical and spherical bubbles, metallic foams

Strategy: maximize uniformity and the efficient use of beam energy by placing center of foil at Bragg peak

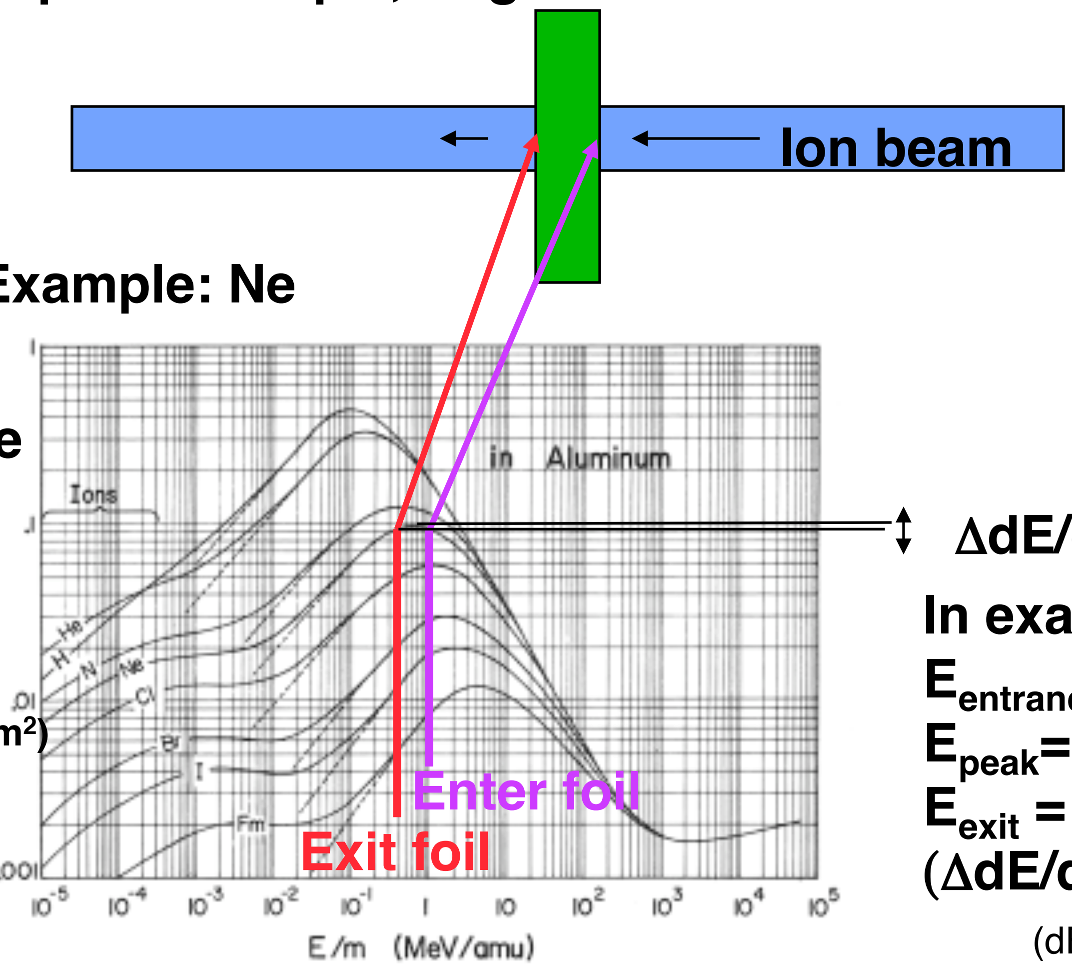
In simplest example, target is a foil of solid or "foam" metal

Example: Ne

Energy loss rate

$$-\frac{1}{Z^2}\frac{dE}{dX}$$

(MeV/mg cm^2)



Energy/Ion mass (MeV/amu)

fractional energy loss can be high and uniformity also high if operate at Bragg peak (Larry Grisham, PPPL)

$\Delta dE/dX \propto \Delta T$

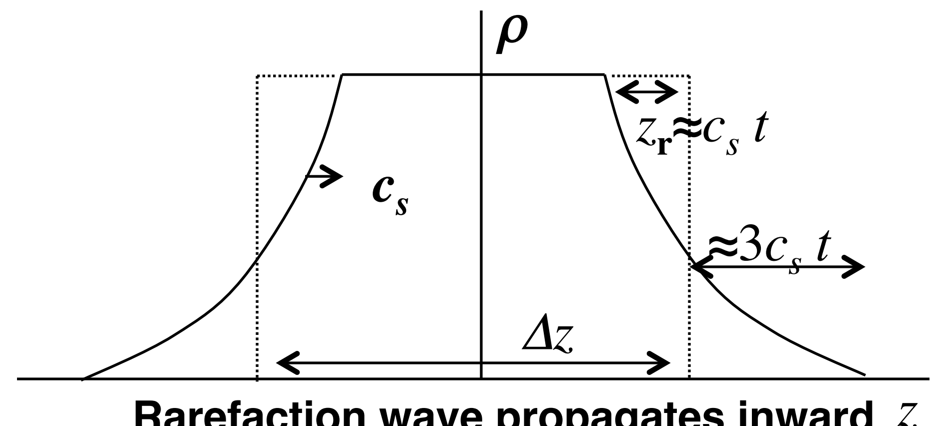
In example,
$E_{entrance}$=1.0 MeV/amu
E_{peak}= 0.6 MeV/amu
E_{exit} = 0.4 MeV/amu
$(\Delta dE/dX)/(dE/dX) \approx 0.05$

(dEdX figure from L.C Northcliffe and R.F.Schilling, Nuclear Data Tables, **A7**, 233 (1970))

Pulse duration must be short to avoid hydrodynamic expansion and cooling

$$\tau_{\text{pulse}} < \Delta z / c_s$$

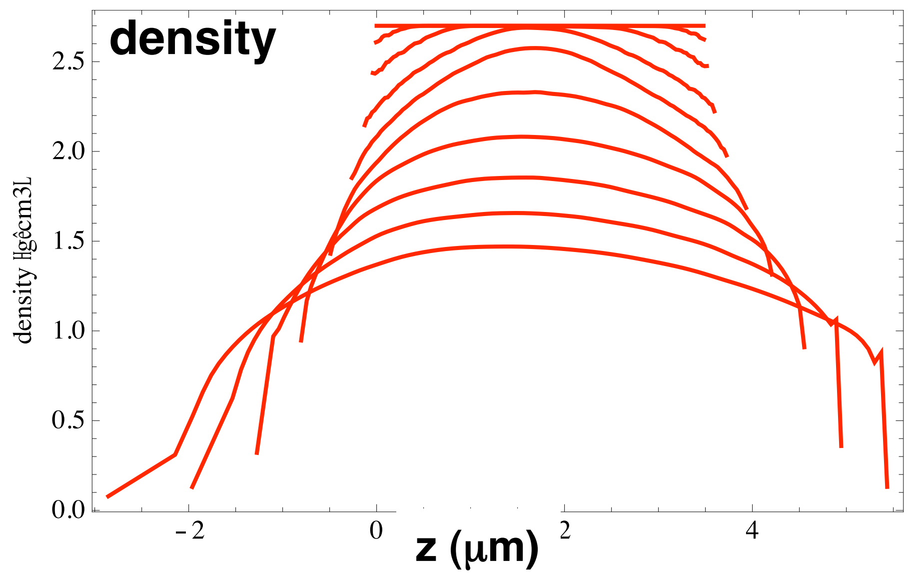
Here: τ_{pulse} = pulse duration
Δz = thickness of target
c_s = sound speed

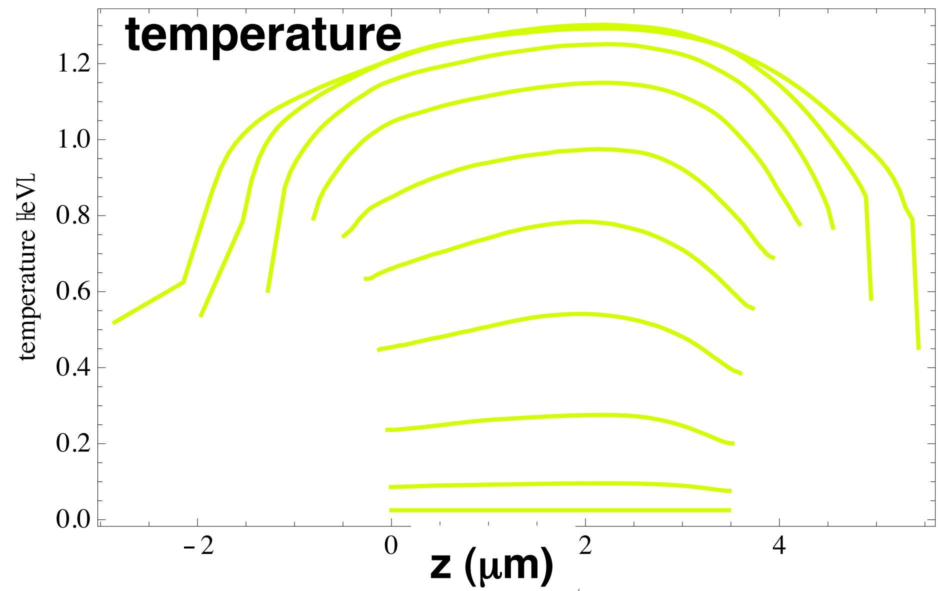


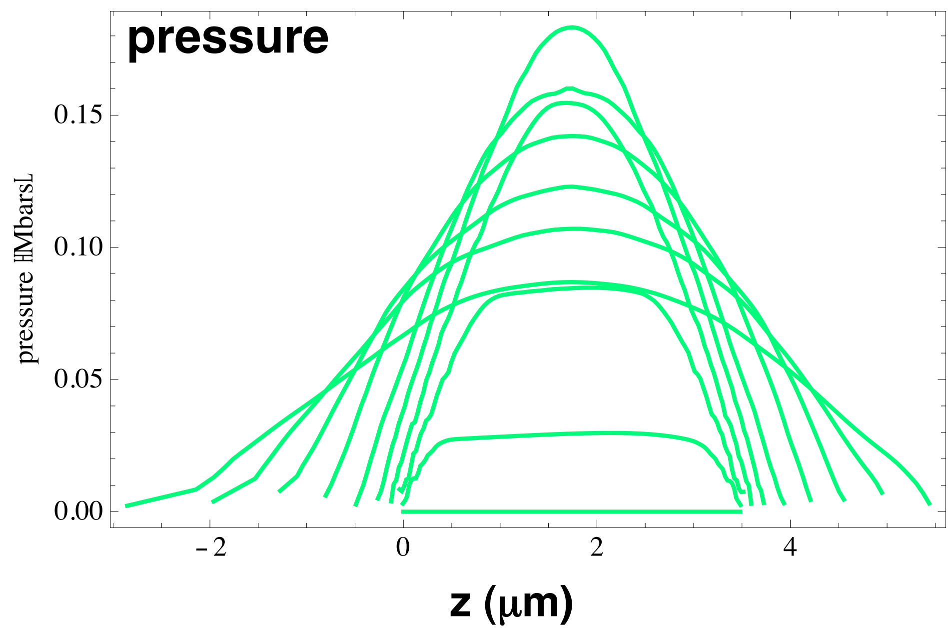
Rarefaction wave propagates inward at c_s (with c_s increasing with time)

The heating pulse should be delivered in a time comparable to or shorter than the time it takes for a rarefaction wave to reach an interior point.

Evolution of center of 3.5 μ thick Al foil over the heating phase (1 ns) using QEOS (assuming NDCX II 21 cells)

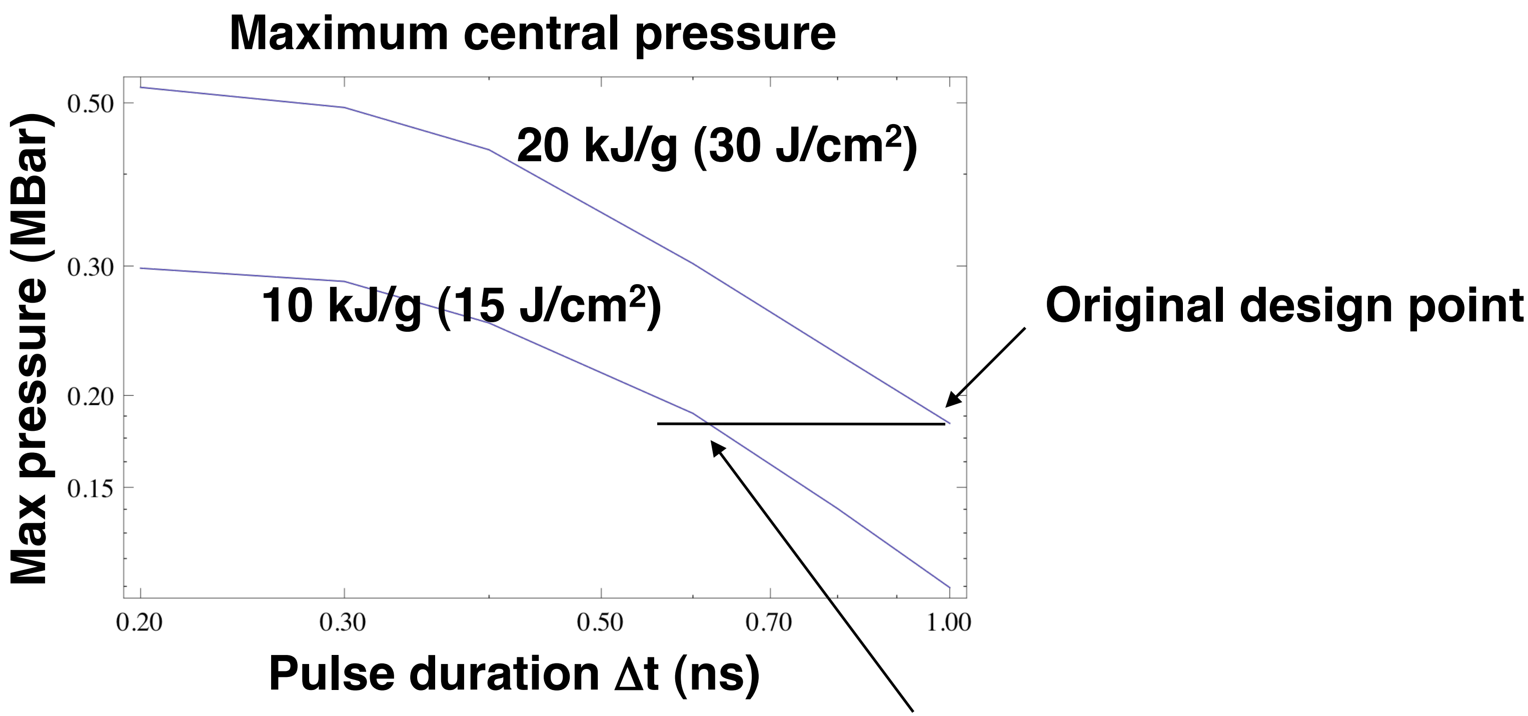






Recent short pulse configurations of NDCX-II reach high pressures at lower fluence via shorter pulse Δt

One figure of merit is central pressure in the foil, since it reflects both high density and high temperature

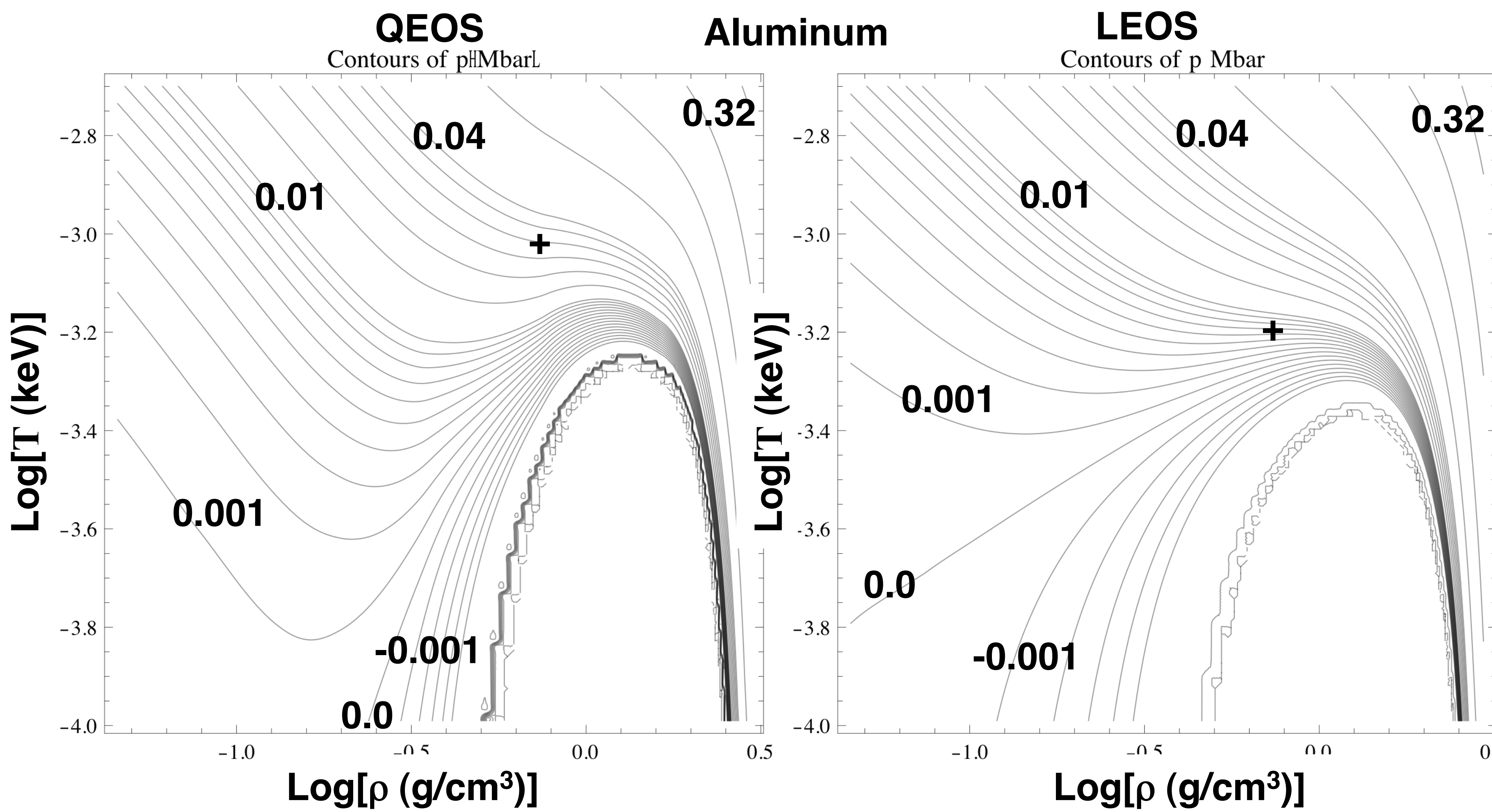


Example: If the pulse duration is reduced to 0.62 ns and the pulse energy reduced to 10 kJ/g, the same central pressure is reached.

NDCX-II potential performance for "well tuned" configurations

	NDCX-I (bunched beam)	NDCX-II construction project			NDCX-II 21-cell (enhanced)
		12-cell (baseline)	15-cell ("probable")	18-cell ("possible")	
Ion species	K^+ (A=39)	Li^+ (A=7)	Li^+ (A=7)	Li^+ (A=7)	Li^+ (A=7)
Total charge	15 nC	50 nC	50 nC	50 nC	50 nC
Ion kinetic energy	0.3 MeV	1.2 MeV	1.7 MeV	2.4 MeV	3.1 MeV
Focal radius (50% of beam)	2 mm	0.6 mm	0.6 mm	0.6 mm	0.7 mm
Duration (bi-parabolic measure = $\sqrt{2}$ FWHM)	2.8 ns	0.9 ns	0.4 ns	0.3 ns	0.4 ns
Peak current	3 A	36 A	73 A	93 A	86 A
Peak fluence (time integrated)	0.03 J/cm^2	13 J/cm^2	19 J/cm^2	14 J/cm^2	22 J/cm^2
Fluence w/in 0.1 mm diameter, w/in duration		8 J/cm^2	11 J/cm^2	10 J/cm^2	17 J/cm^2
Max. central pressure in Al target		0.07 Mbar	0.18 Mbar	0.17 Mbar	0.23 Mbar
Max. central pressure in Au target		0.18 Mbar	0.48 Mbar	0.48 Mbar	0.64 Mbar

WDM experiments: An example of two significantly different equations of state

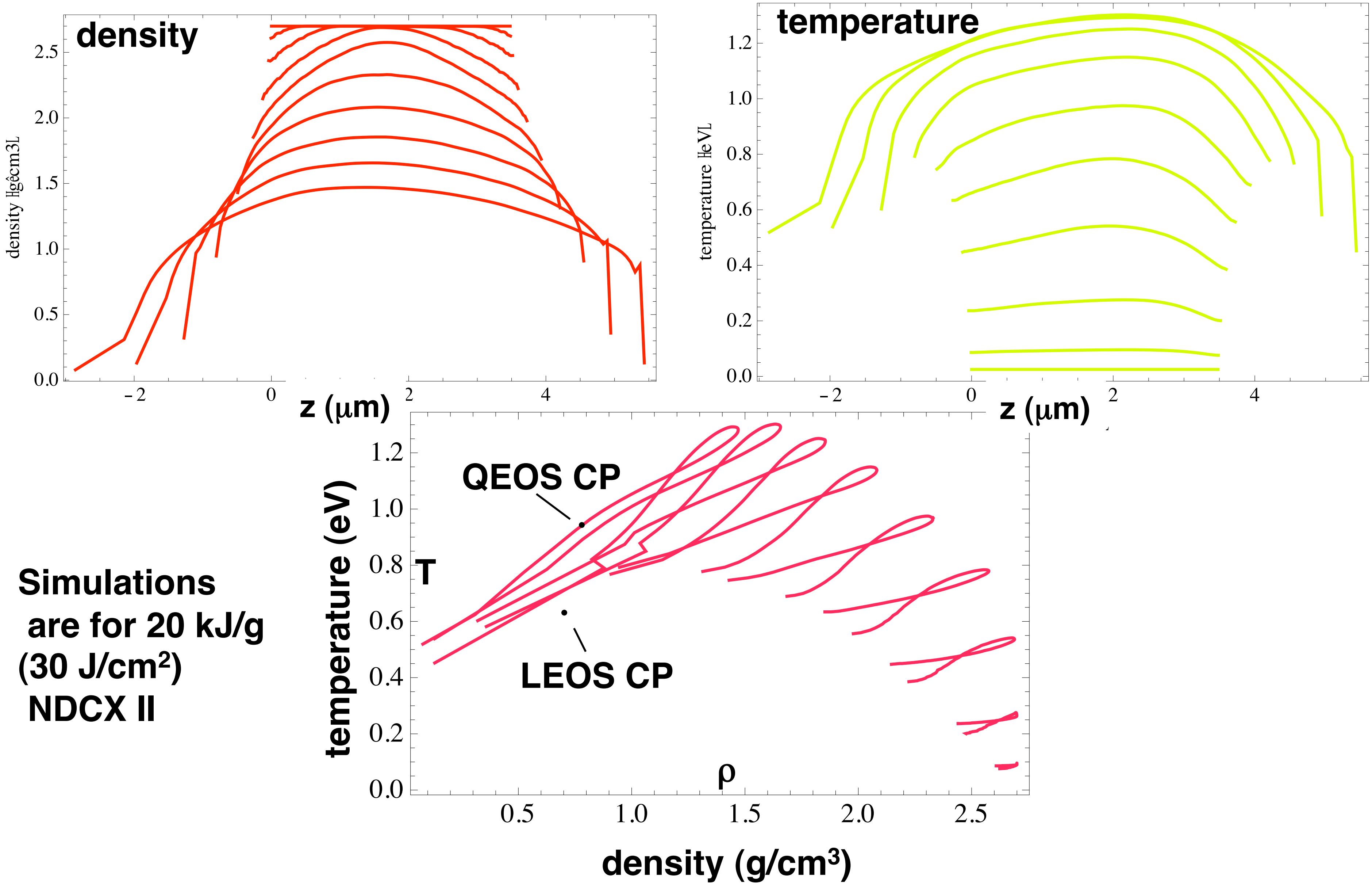


Critical point:
p=0.029 MBar
ρ=0.78 g/cm³
T=0.945 eV

Theories and experiments place critical point between 5500 K and 12000 K (0.5 eV and 1.0 eV)

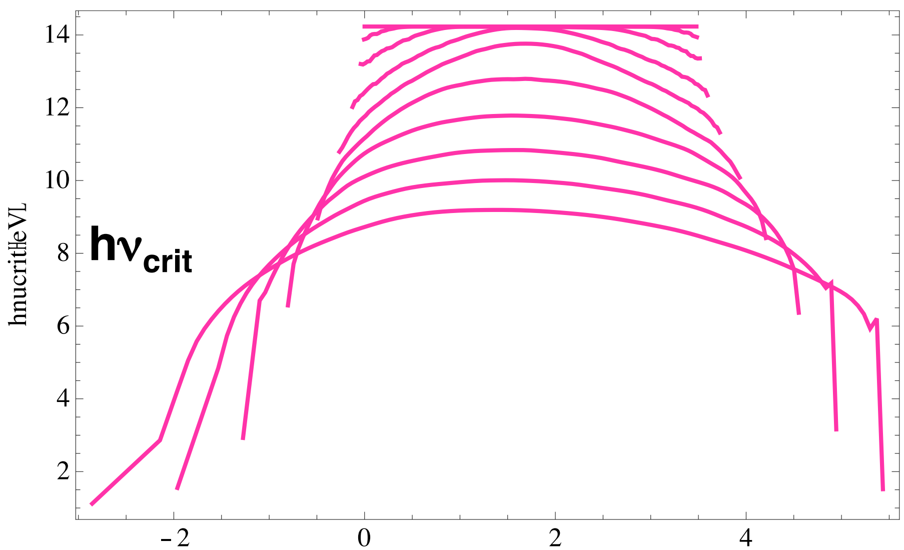
Critical point:
p=0.0065 MBar
ρ=0.70 g/cm³
T=0.633 eV

Evolution of center of 3.5 μ thick Al foil over the heating phase (1 ns) using QEOS (using NDCX II 21 cells)



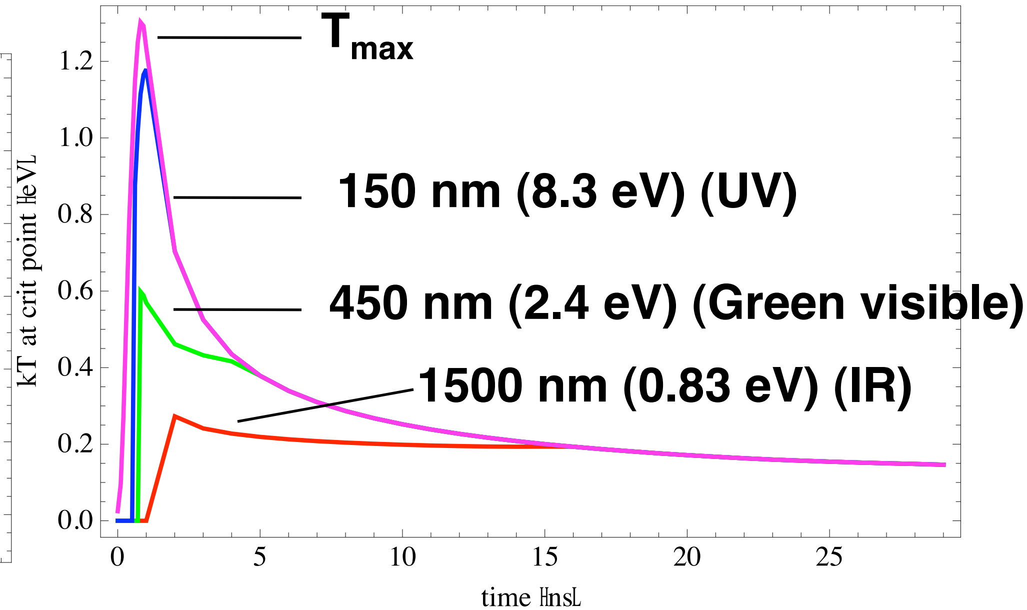
Simulations are for 20 kJ/g (30 J/cm²) NDCX II

Evolution of the temperature T_b at the critical density for different observation frequencies



z (microns)

$\nu_{crit} = \omega_p/2\pi$;



Model assumes:

$T_b = T(h\nu_{crit})$ if $h\nu_{critmin} < h\nu < h\nu_{critmax}$

$T_b = T_{max}$ if $h\nu > h\nu_{critmax}$

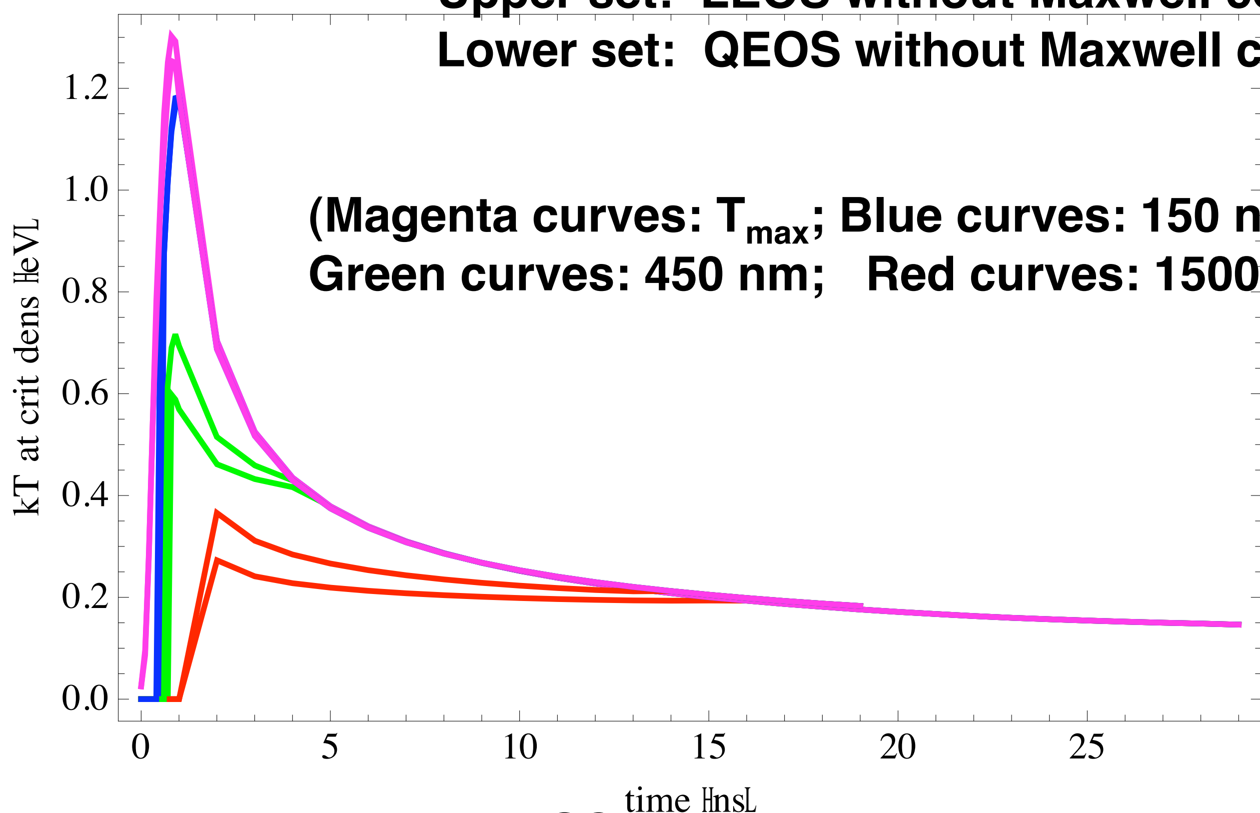
$T_b = 0$ if $h\nu < h\nu_{critmin}$

Pyrometry measurements of T_b will have significantly different profiles at different frequencies

We may compare two equations of state

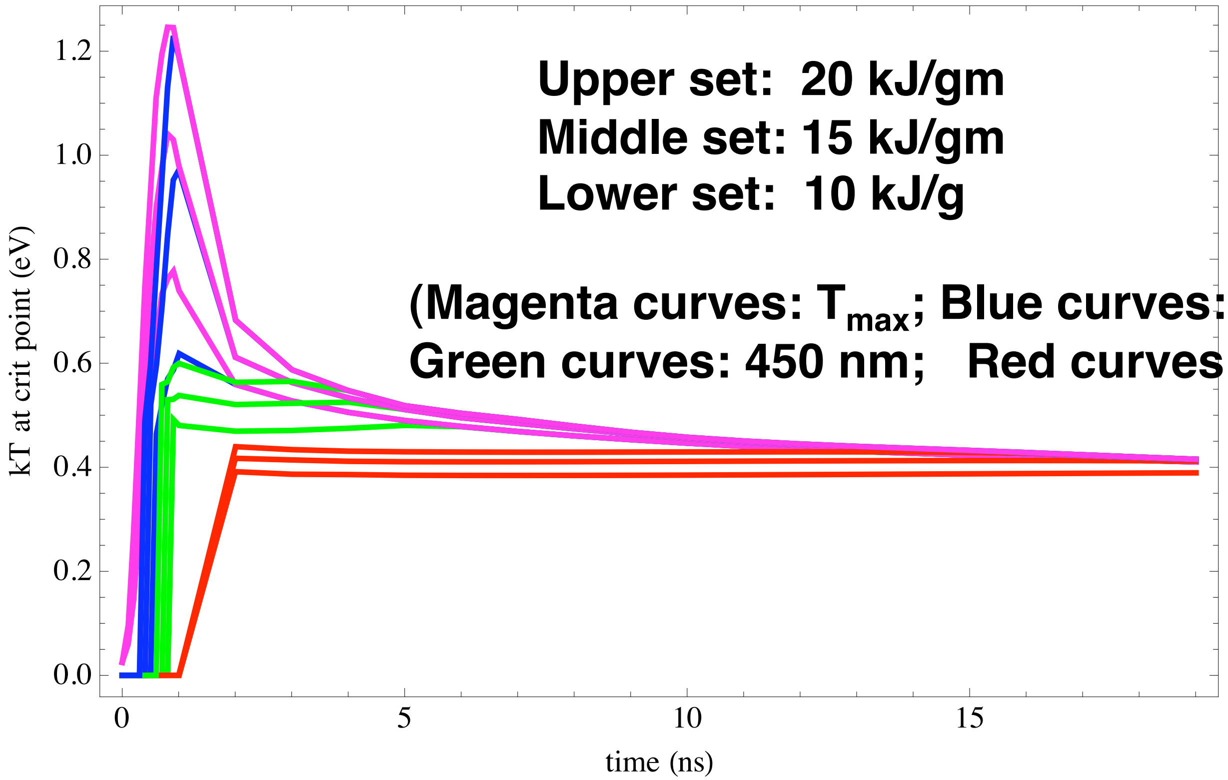
Upper set: LEOS without Maxwell construction
Lower set: QEOS without Maxwell construction

(Magenta curves: T_{max}; Blue curves: 150 nm
Green curves: 450 nm; Red curves: 1500 nm)



IR is most sensitive to the EOS, and the two EOS should be distinguishable

We may compare the same plots for different intensities

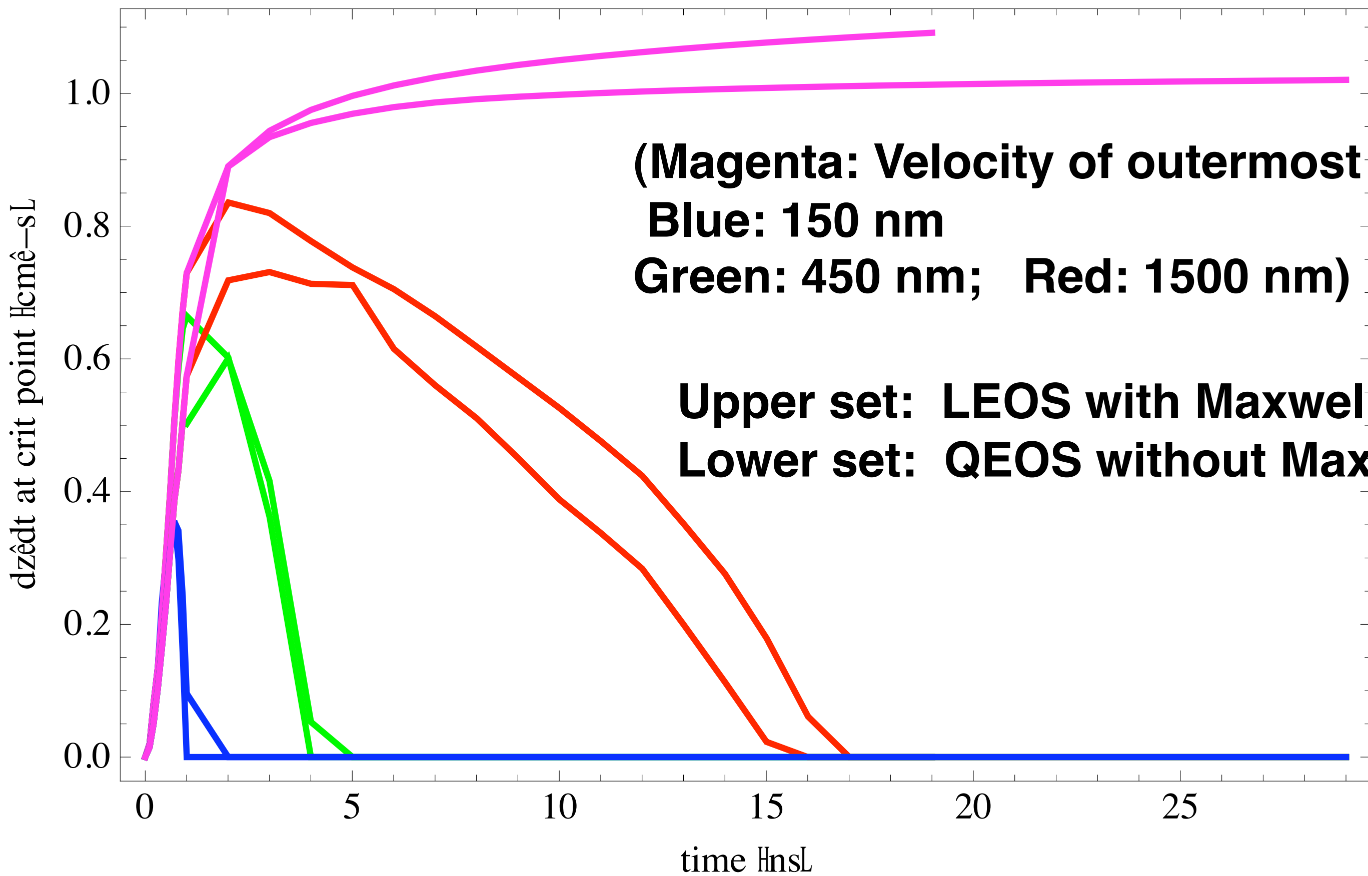


Upper set: 20 kJ/gm
Middle set: 15 kJ/gm
Lower set: 10 kJ/g

(Magenta curves: T_{max}; Blue curves: 150 nm
Green curves: 450 nm; Red curves: 1500 nm)

(UV most sensitive to change in deposited energy;
IR (which samples cooler part of blowoff, less sensitive)

The velocity at the critical density as would be observed by a VISAR would also distinguish between different EOS

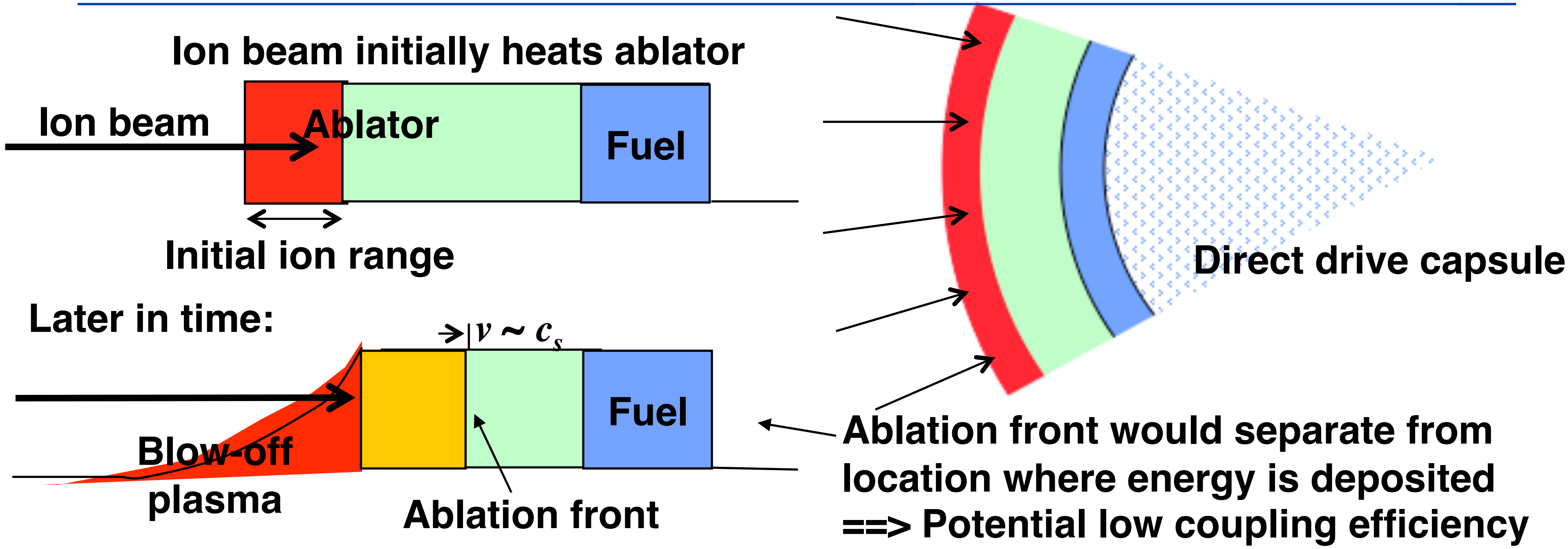


(Magenta: Velocity of outermost zone;
Blue: 150 nm
Green: 450 nm; Red: 1500 nm)

Upper set: LEOS with Maxwell construction
Lower set: QEOS without Maxwell construction

Again, the IR is best suited for distinguishing different EOS

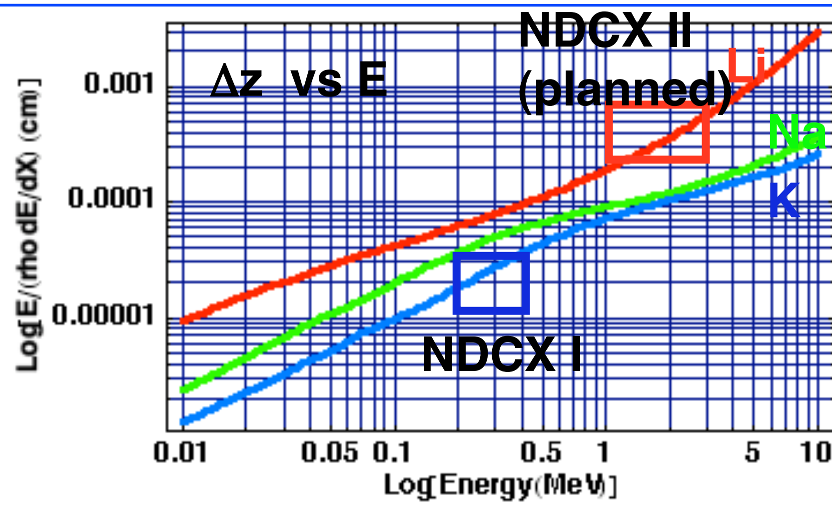
NDCX II will also study ion beam coupling physics that is relevant to high gain direct drive targets for Inertial Fusion Energy



Ramping ion beam energy over the course of the pulse, will increase ion range allowing efficient coupling of beam energy into kinetic energy of fuel shell

To "follow a shock," the energy ramping in NDCX II must be sufficiently fast

$$\Delta z \approx 2\mu\left(E/1\ \text{MeV}\right)$$ **(solid Al)**

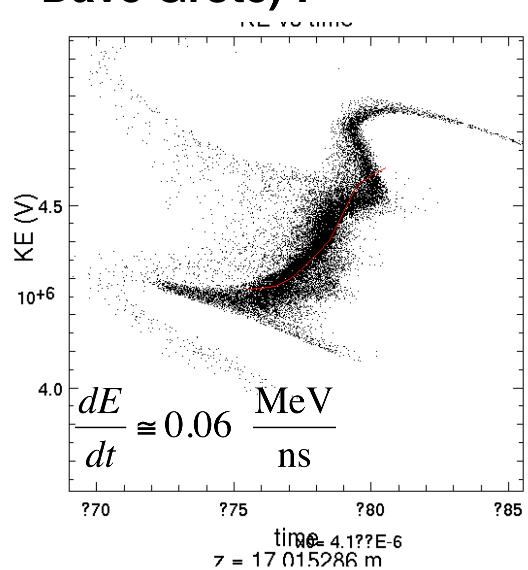


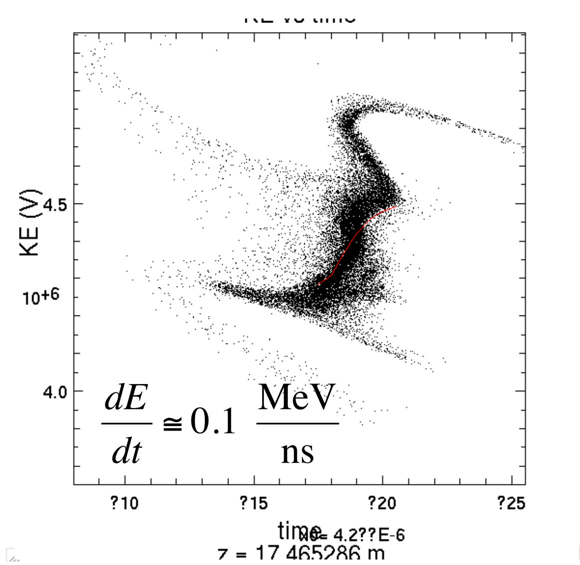
To keep pace with the shock, (where $v_{shock} \sim c_s$) the energy slew must satisfy:

$$\frac{dE}{dt} = E\frac{c_s}{\Delta z} \cong 2.5\ \frac{\text{MeV}}{\text{ns}}$$ **(solid Al)**

$$\frac{dE}{dt} \cong 0.10\ \frac{\text{MeV}}{\text{ns}}$$ **(10% Al foam)**

Initial look at energy slew rate on NDCX II (courtesy Dave Grote) :

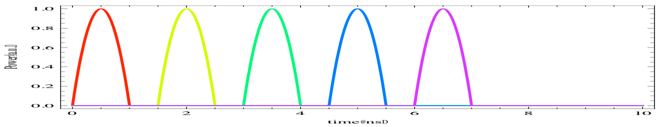


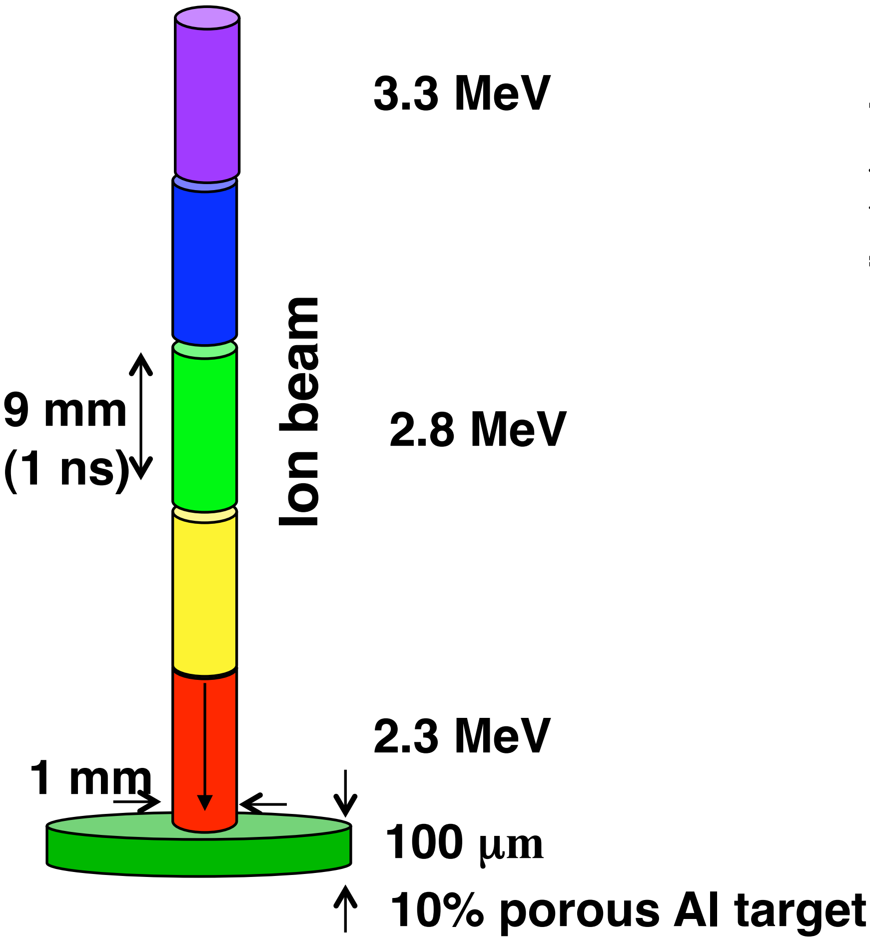


Placing foil upstream of best focus is simplest way to achieve energy ramp.

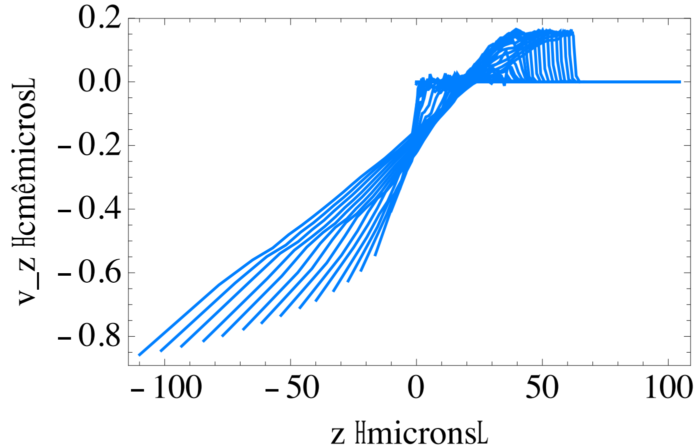
Using metallic foams or low density solids (e.g. LiH) could meet energy ramp requirement

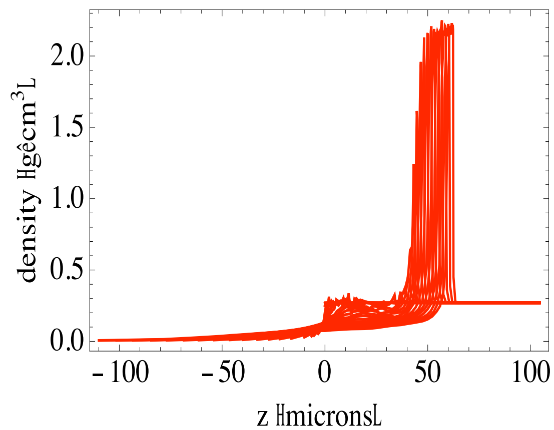
HYDRA simulations show that experiments on NDCX II can demonstrate benefits of energy ramp on coupling





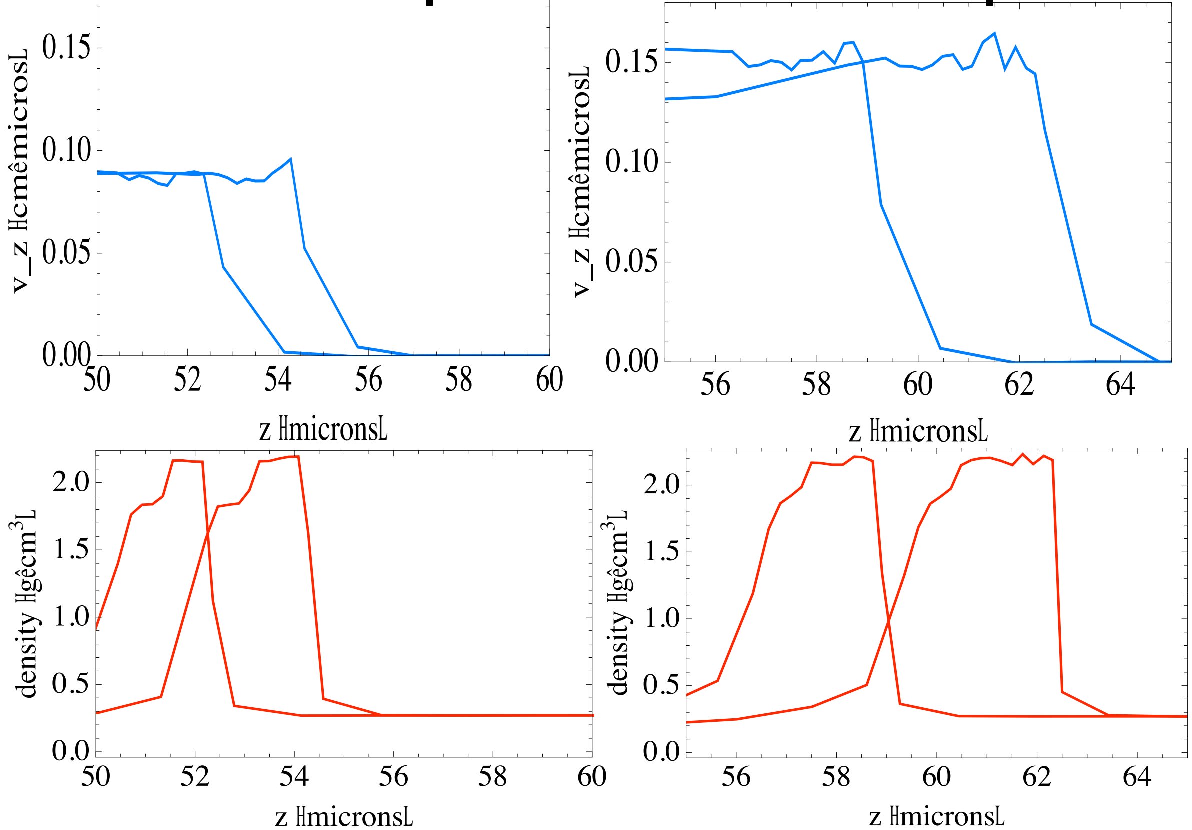
6 ns "macro-pulse"

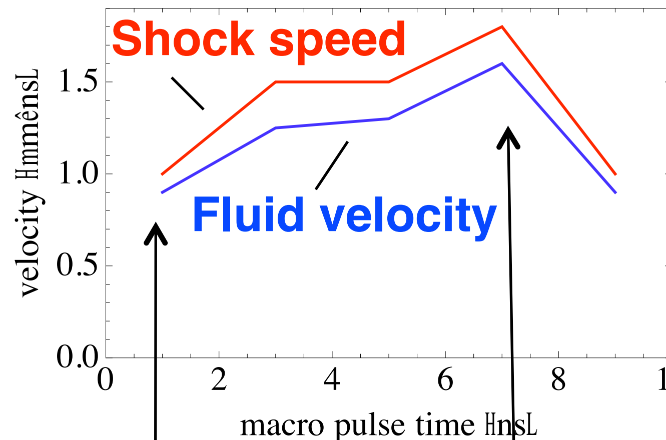




Shock positions at 18 and 20 ns illustrate the "sweet spot" at optimal slew rate

1 ns "macro-pulse" | **7 ns "macro-pulse"**



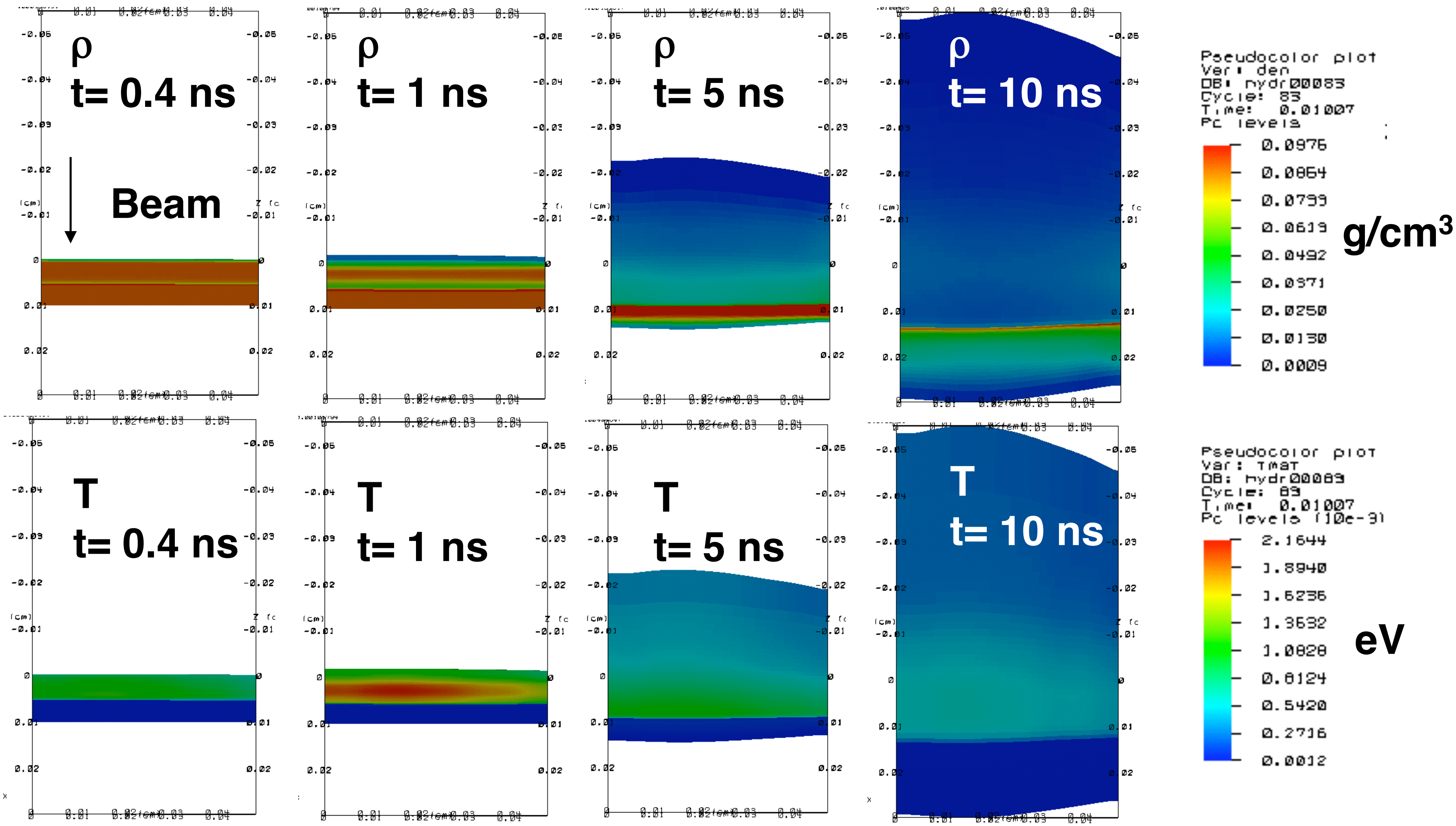


At longitudinal focus

At optimal slew rate

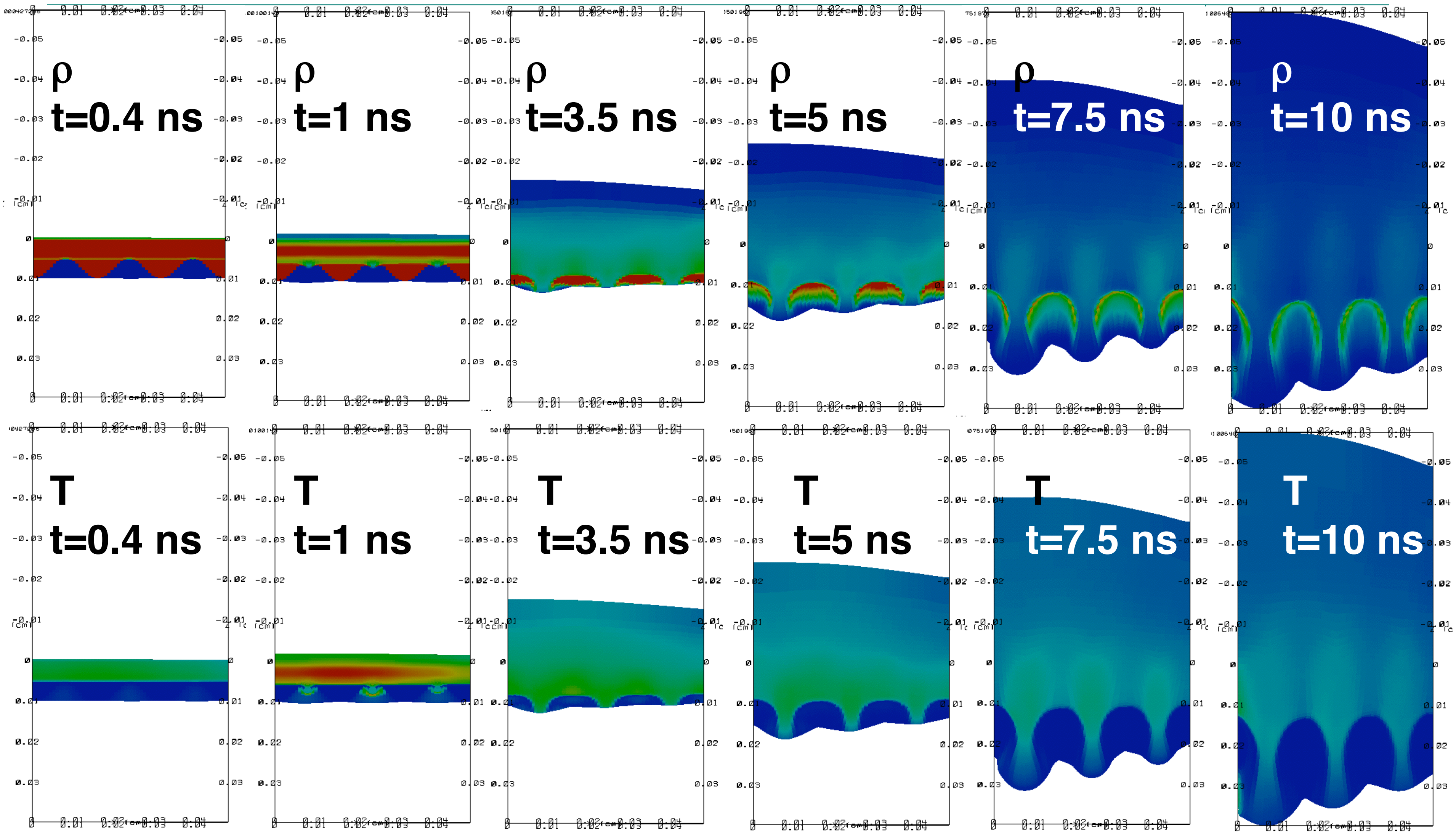
	1 ns	7 ns
V_shock =	1.0 μ/ns	1.8 μ/ns
V_fluid =	0.9 μ/ns	1.6 μ/ns
ρ_fluid =	2.2 g/cm³	2.2 g/cm³

HYDRA simulations using advanced NDCX-II parameters simulate possible hydrodynamic stability experiments particular to ions

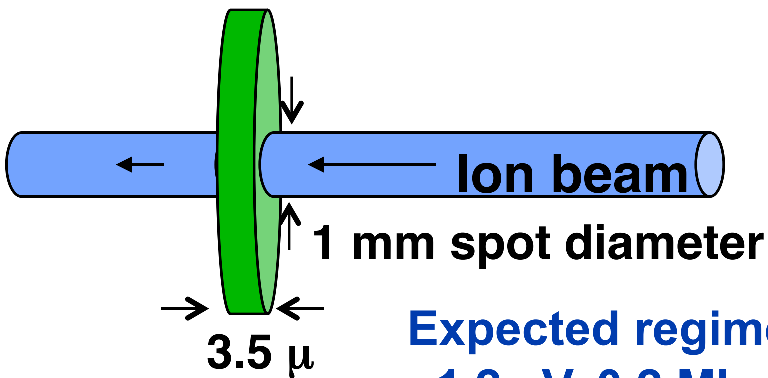


23 MeV Ne, 0.1 μC, 1 ns pulse (NDCX II) impinges on 100 μ thick solid H, T=0.0012eV, ρ =0.088 g/cm3; No density ripple on surface, blowoff accelerates slab

When initial surface ripple is applied, evidence for hydro instability is apparent



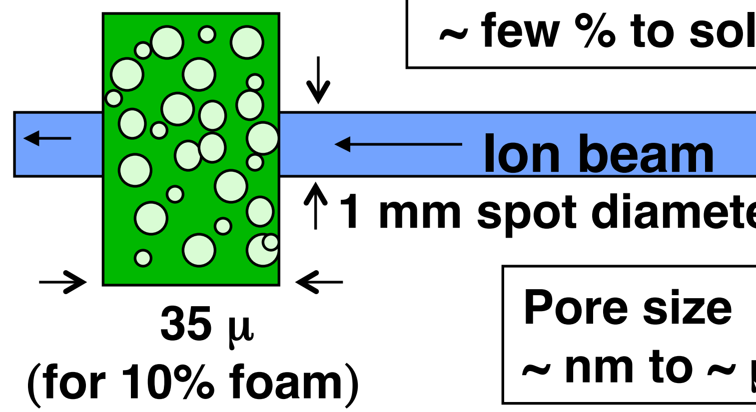
Several target options have been considered for WDM and IFE studies on NDCX II



Expected regime:
~1.2 eV, 0.2 Mbar

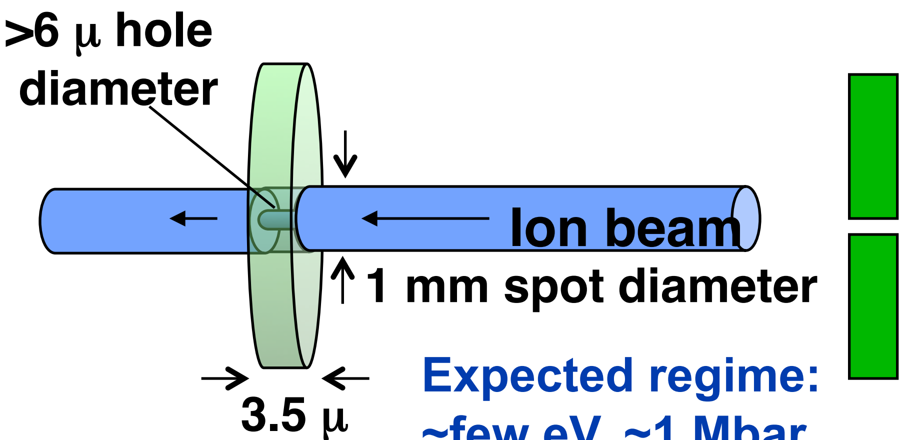
Solid planar targets

Foam densities
~ few % to solid



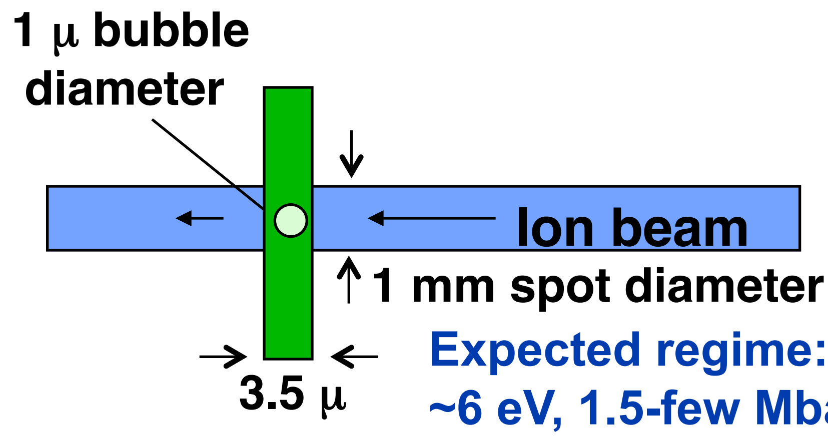
Pore size
~ nm to ~ μm

Foam planar targets



Expected regime:
~few eV, ~1 Mbar

Cylindrical "bubble" targets



Expected regime:
~6 eV, 1.5-few Mbar

Spherical bubble targets

Conclusions

NDCX II will be useful for both Warm Dense Matter (WDM) and Heavy Ion Fusion (HIF) applications

Recent accelerator designs achieve high pressures by reaching shorter pulse durations than initially anticipated but at lower ion energy and fluence

For WDM, NDCX II pyrometry experiments should be able to distinguish between specific equations of state (for example, QEOS and LEOS). VISAR experiments may also be able to distinguish different EOS.

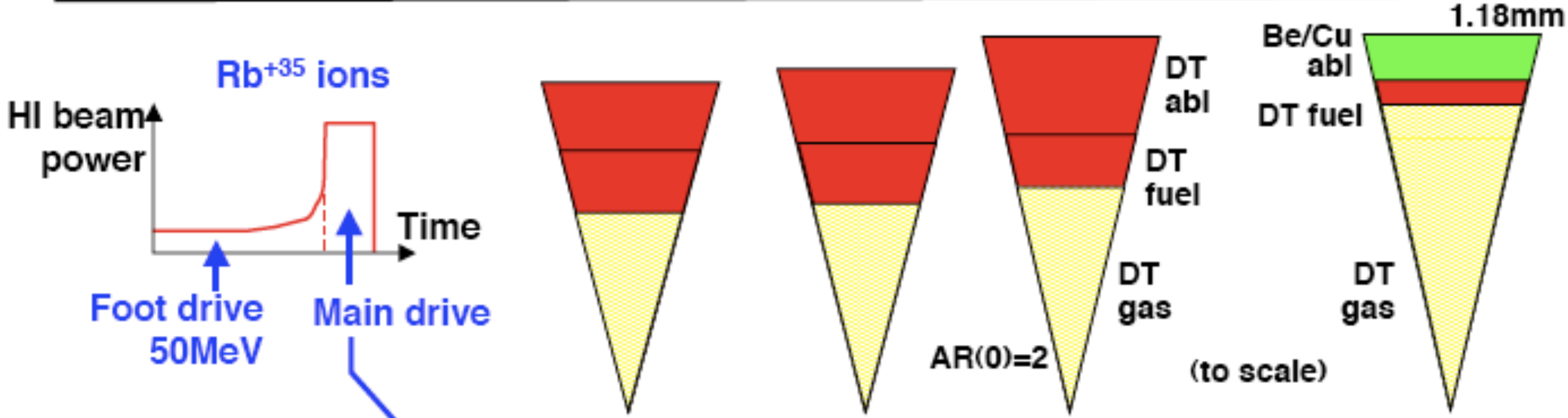
For HIF, we are exploring direct drive concepts that have high coupling efficiency, by utilizing ramped ion energy with increasing range. NDCX II will be able explore a key aspect of direct drive target concept: changing ion energy to keep ion deposition point close to shock front. Hydrodynamic stability experiments may also be achievable for some NDCX-II parameters

Several target geometries lead to interesting material conditions

- planar targets at ~ 1 eV, .5 MBar (in Al) are predicted;
- cylindrical and spherical imploding bubbles will reach higher central temperatures and pressures, and probe ion driven hydro

Foam dynamics are of interest for both WDM and HIF applications.

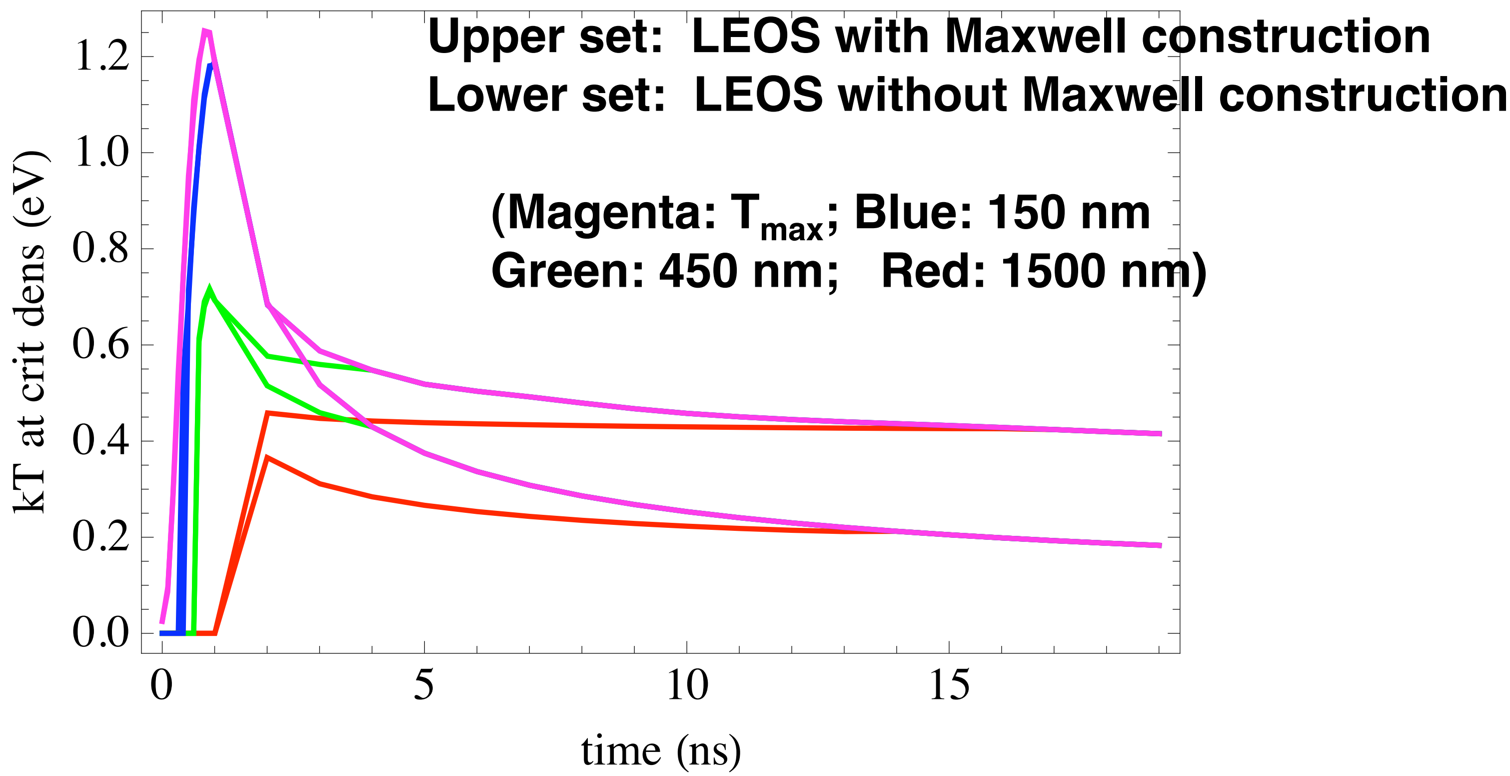
Recent heavy ion capsule designs by Perkins show NIF target yields at 1/4 to 1/3 the driver energy of NIF



	50MeV	200MeV	500MeV	NIF
$m_{ablator}/m_{fuel}$	1.8	2.1	3.0	18
Driver energy (MJ)	0.32	0.36	0.44	1.3
Peak drive power (TW)	175	195	205	320
Yield (MJ) / Gain	24.7 / 77	21.6 / 60	20.8 / 47	20.0 / 15
$\eta_{absorbed}$ / η	0.97 / 0.10	0.91 / 0.10	0.88 / .09	0.16 / 0.02
In-flight aspect ratio	25	27	25	32
Convergence ratio	35	30	31	34
In-flight adiabat α	1.9	2.4	3.2	1.4

(from J. Perkins et al, Hirschegg Presentation, 2009).

We may also compare the same equation of state with or without the Maxwell construction



Now IR is VERY sensitive to the choice of Maxwell construction or no Maxwell construction. [Maxwell construction = equilibrium, (true for small droplets, but for big?); Non-maxwell construction = microscopically valid, but, simulation has insufficient spatial resolution to resolve small drops).

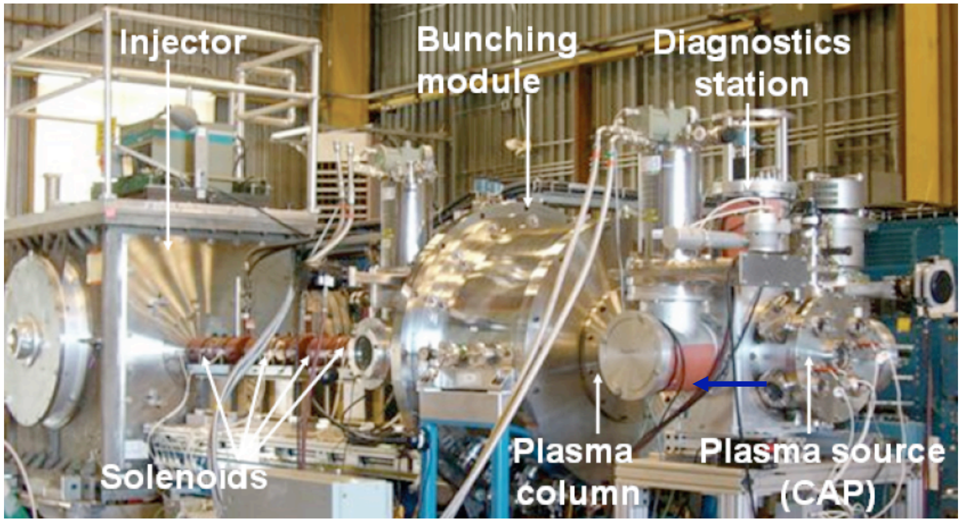
NDCX I is laying the groundwork for NDCX II

NDCX I

0.35 MeV

0.003 μC

Now



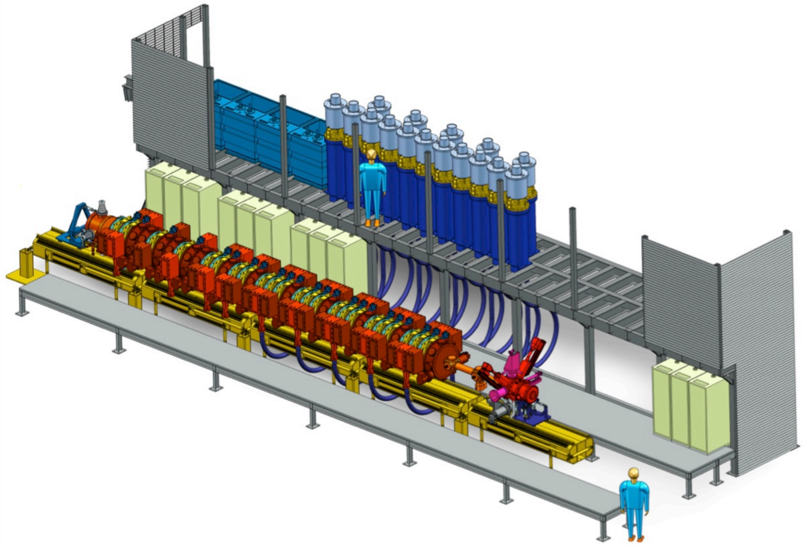
- Explore metal liquid/vapor boundaries at T ~ 0.4 eV
- Evaporation rates/ bubble and droplet formation
- Test beam compression physics
- Test diagnostics

NDCX II

~2 MeV (initial config.)

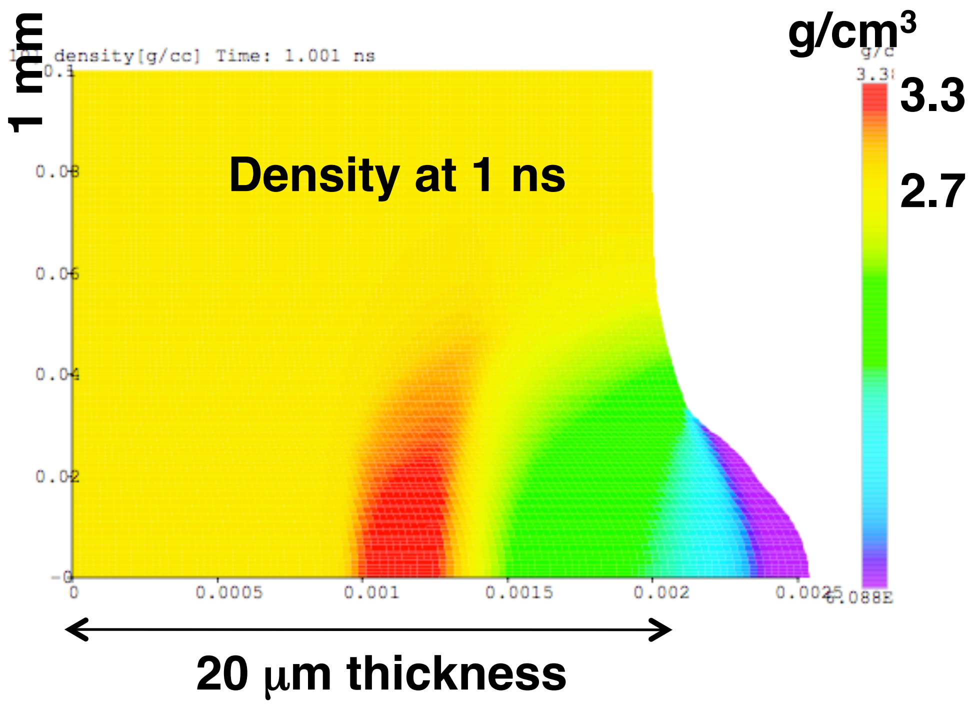
0.03 μC

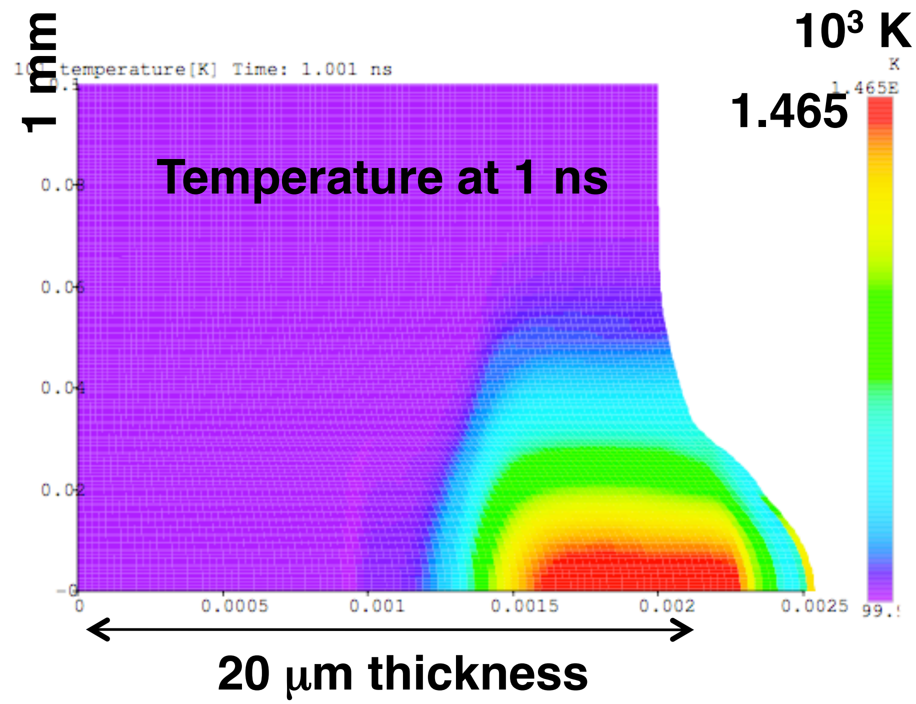
2012



- Bragg peak (uniform) heating
- T ~1-2 eV in planar metal targets (higher in cylindrical/spherical bubble implosions)
- Ion+/Ion- plasmas; porous targets
- Critical point; complete liquid/ vapor boundary; EOS
- Transport physics (e-cond. etc)
- HIF coupling and beam physics

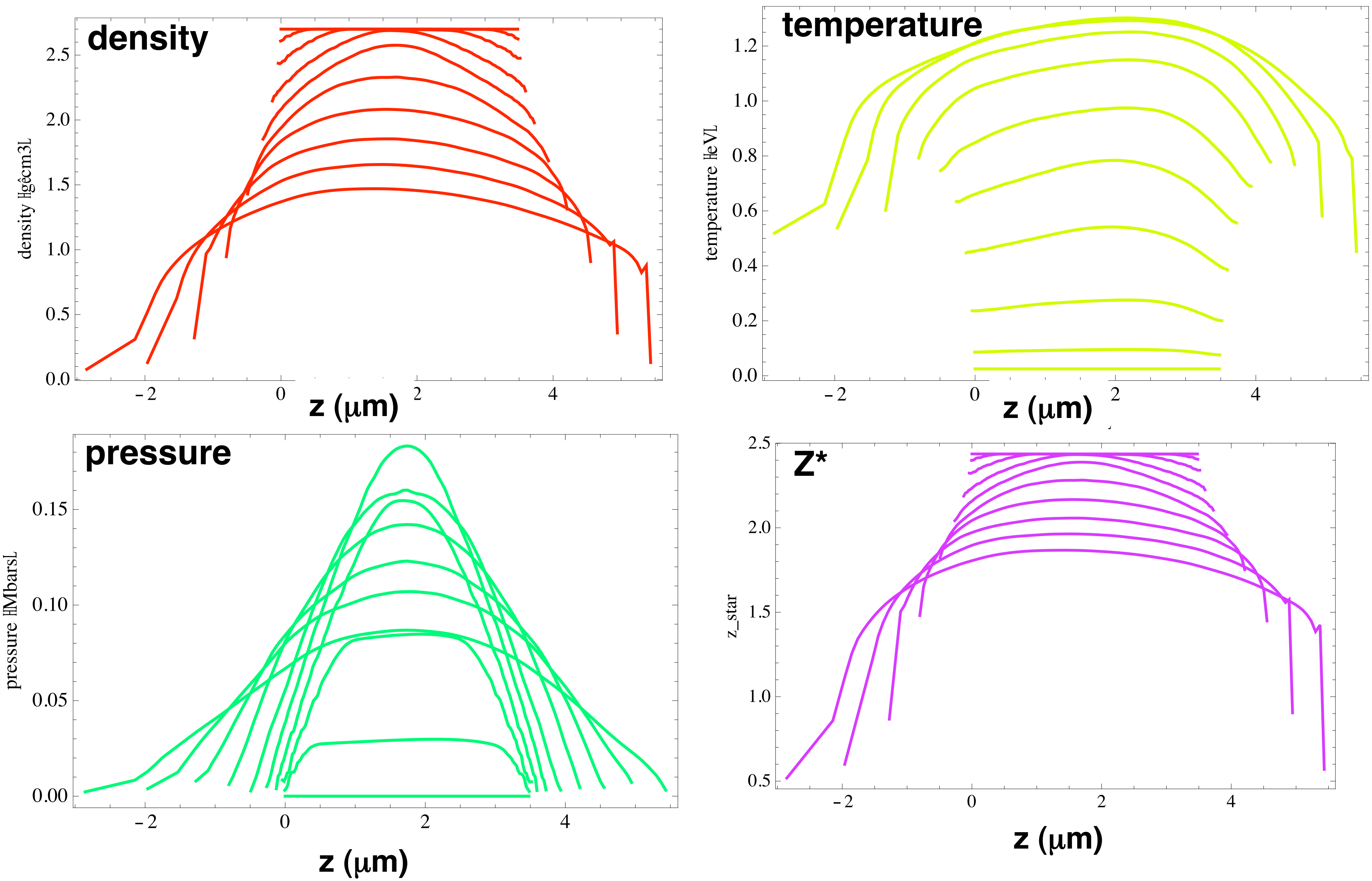
A. Ng (U. B.C.), N. Tahir (GSI), R. Piriz (U. de Castilla) and the VNL have begun a collaboration to evaluate the use of beam generated shocks to study WDM on NDCX II.





Initial simulations by Tahir find peak temperatures of 1.2 eV in Al; 2.5 eV in W
Peak pressures of 0.32 MBars in Al; 0.6 MBars in W
Tampers and flyers will be evaluated.

Evolution of center of 3.5 μ thick Al foil over the heating phase (1 ns) using QEOS (assuming NDCX II 22 cells)



Collaborators in the theory/simulation effort

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Results using simple theory are suggestive; need a more rigorous theory for precision WDM measurements

To make this "streaked optical pyrometry" a more quantitative tool, we need improved theory of emission: Can we unfold the unknown emissivity $e(\lambda,\theta)$ for WDM target material?

For simple cases (homogeneous target material) "emissivity = absorptivity" (Kirchoff's law). After hydrodynamic expansion, something better is needed.

In the VNL, we have two strategies for this question:

1. Develop polarization pyrometry (measure 2 polarizations at non-normal angles) to increase data collected in each experiment

2. First-principles code for emission of visible light from overdense plasma surface having strong density gradient; equations for arbitrary dielectric function $\varepsilon(\omega)$.

Theory of visible light emission from overdense plasma with strong surface gradients is near completion

Key issues:

1. Strong angle dependent polarization of emitted light. Tested in experiments at LBNL, Tokyo (UEC) and NIFS (Toki) using electrically -heated, laser heated, and e-beam heated metals

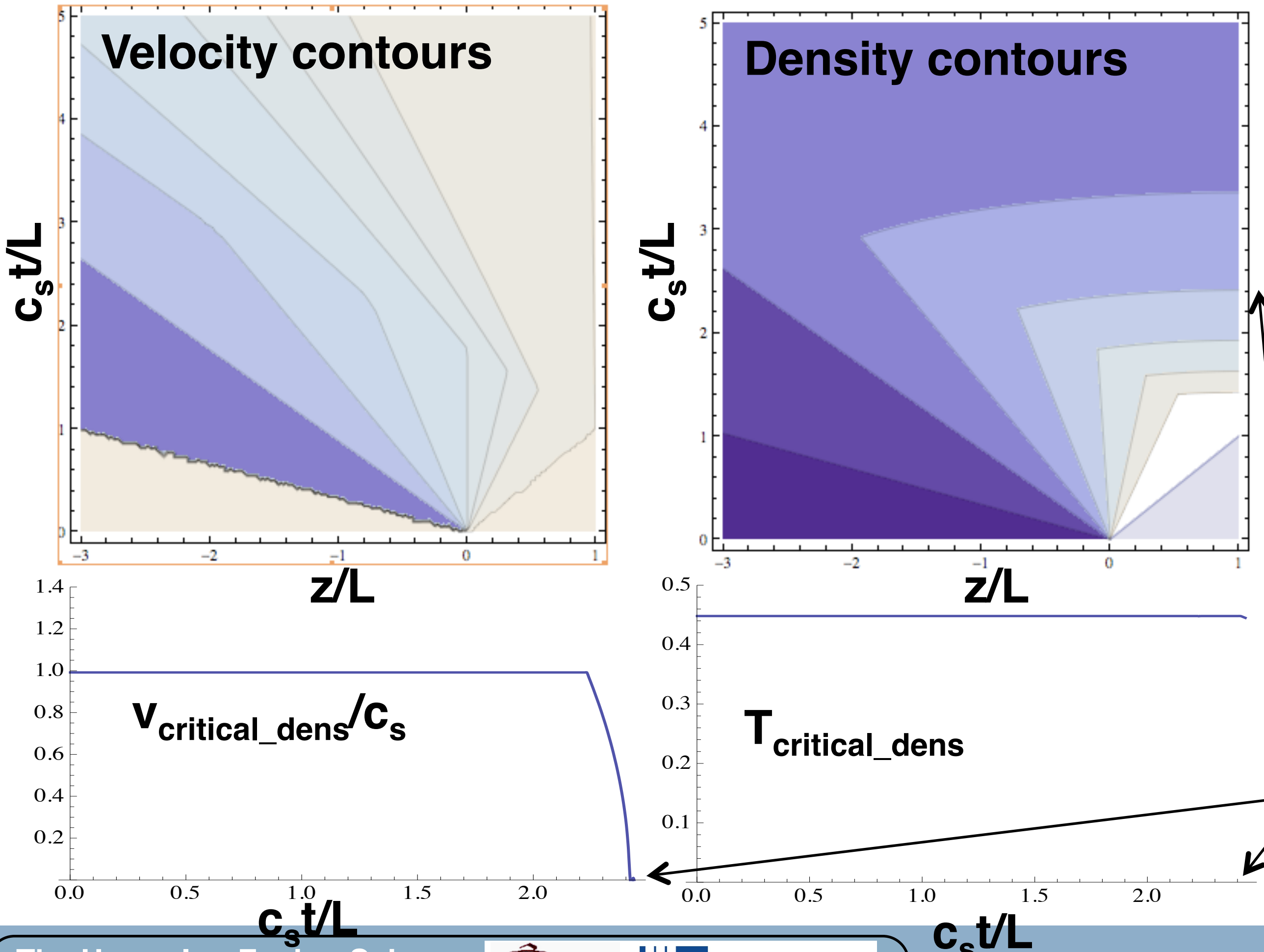
2. Detailed balance and connection to laser absorption, ellipsometry theory. These connections are a check of the emission theory.

3. How rapidly does the polarization effect disappear with:
Temperature gradients in the near-surface region?
Surface roughness or non-uniform expansion?

Preliminary results have been presented by R. More at the International Workshop on WDM, (Hakone, Japan, March 2009) and the 19th Toki Conference on Advanced Physics in Plasmas and Fusion (Toki, Japan, December 2009)

We may also calculate the velocity at the critical density for a particular photon frequency as a function of time

Again looking at the idealized case (instantaneous heating, ideal gas, constant Z*):



The velocity contours first align with, then cross the density and temperature contours, so the velocity measured at the critical density would first be constant then plummet

Time at which density contour reaches z=1 (central) axis

NDCX II will serve as a platform for warm dense matter experiments and as a test bed for heavy ion fusion

1. Experimental concepts for Warm Dense Matter (WDM)

   a. planar solid targets
   b. metallic foams
   c. cylindrical and spherical "bubbles"

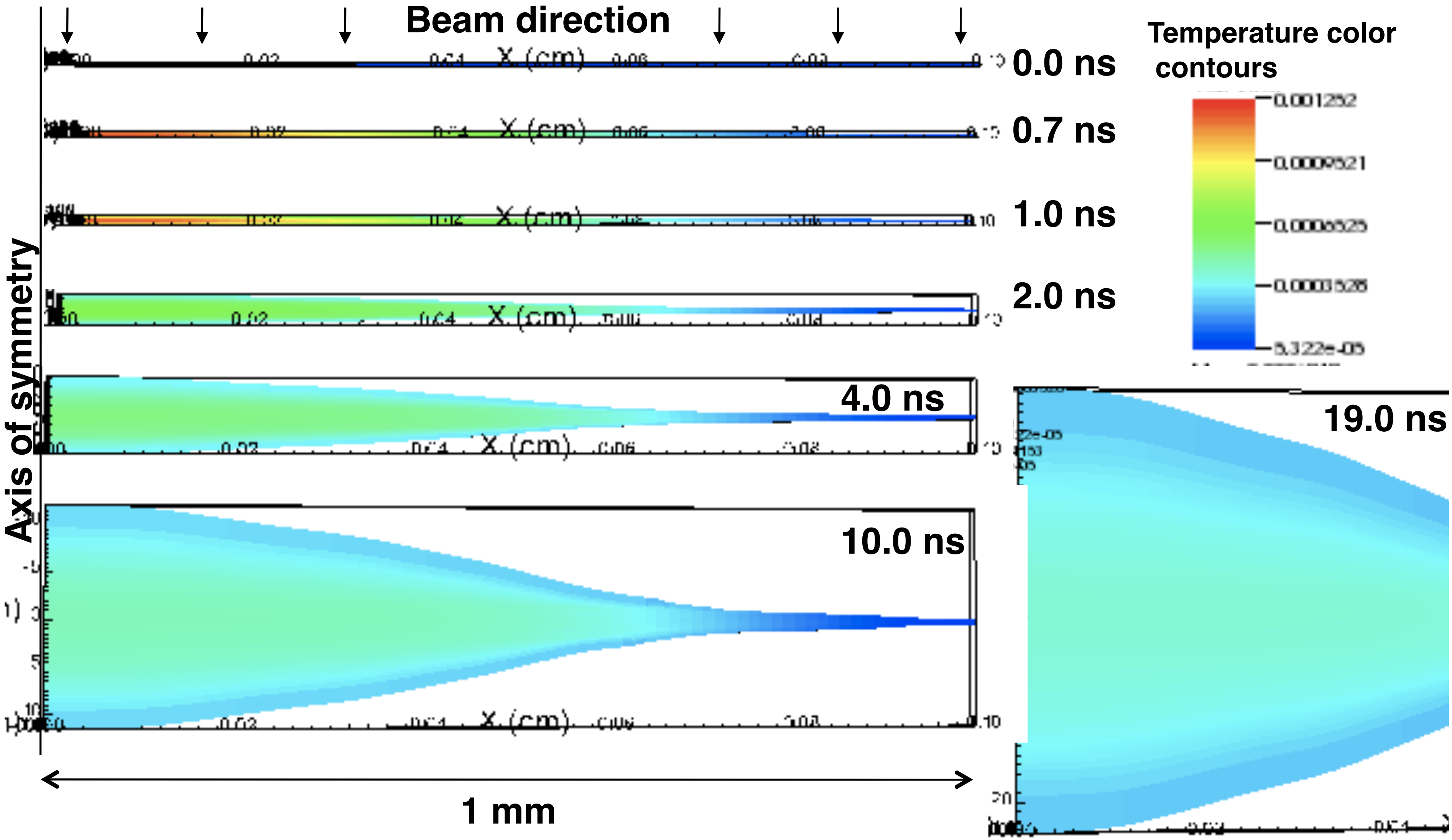
2. Connecting simulations of WDM targets to diagnostics

   a. simulating brightness temperature at critical density point
   b. simulating velocity at critical density point

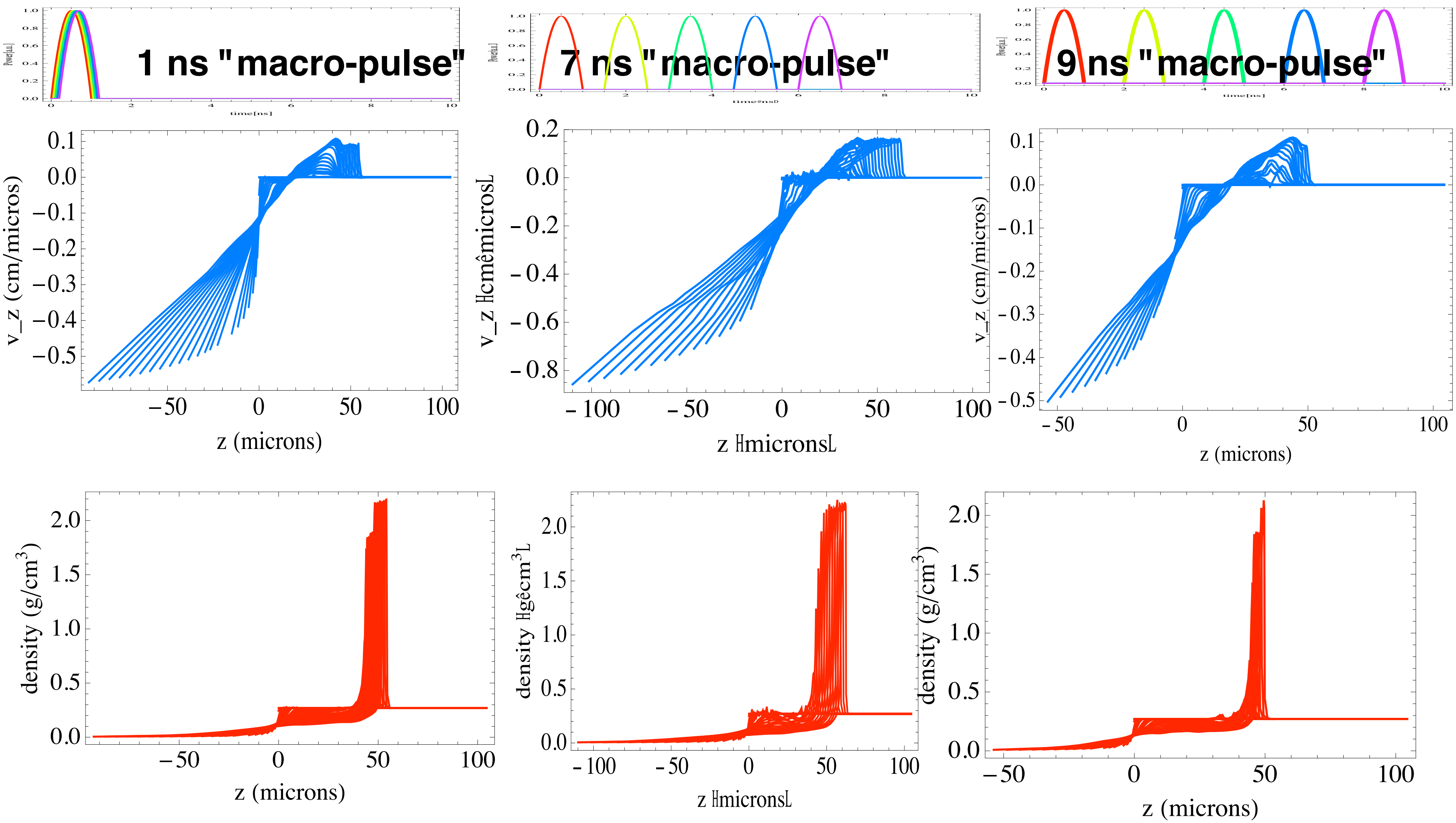
3. Simulations of experiments relevant to Heavy Ion Fusion (HIF)

   a. coupling physics: two-pulse/ ramped pulse experiments

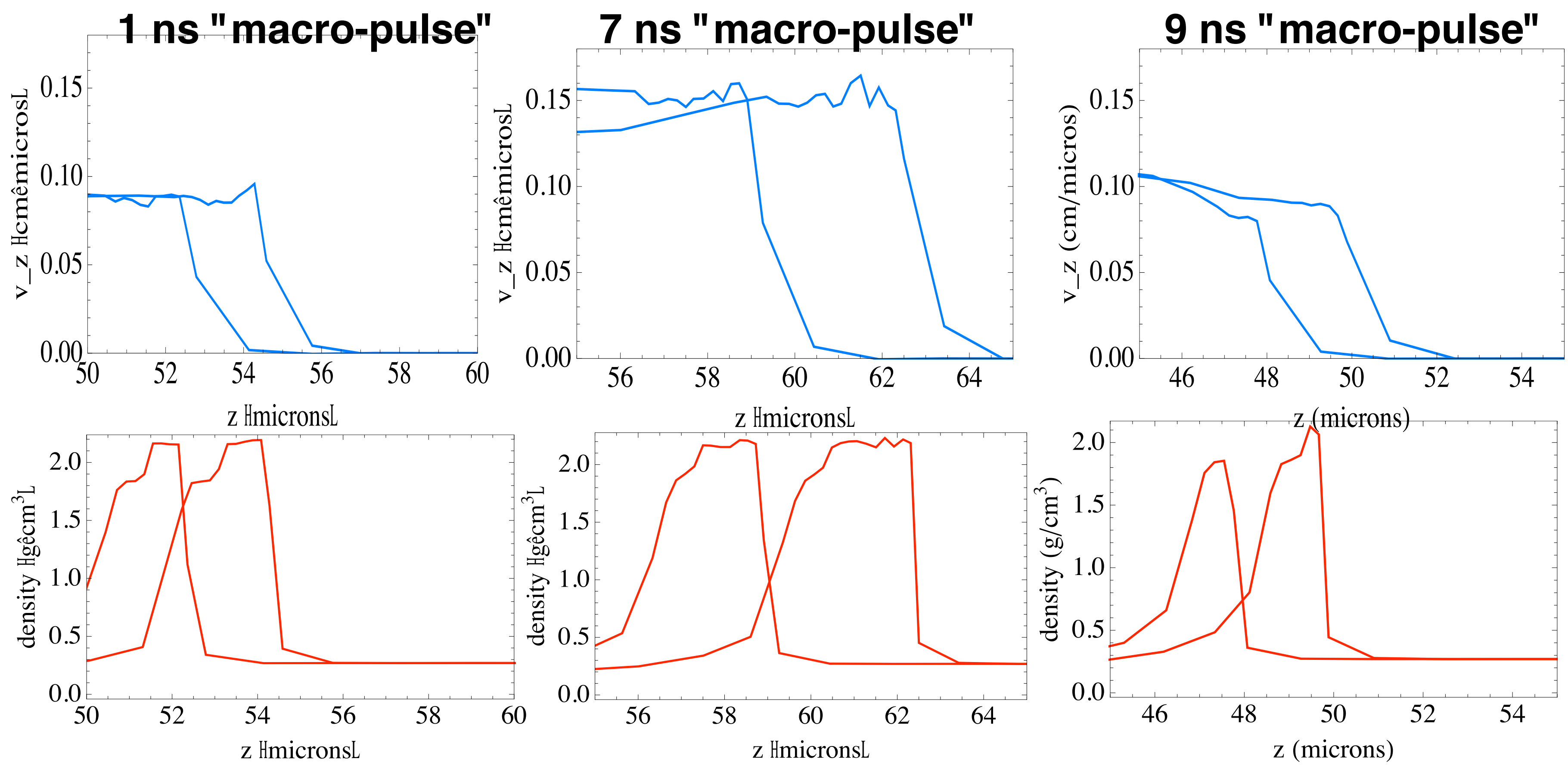
2D HYDRA simulations show the long term expansion of the foil and evolution with radius



HYDRA simulations show that experiments on NDCX II can demonstrate benefits of energy ramp on coupling

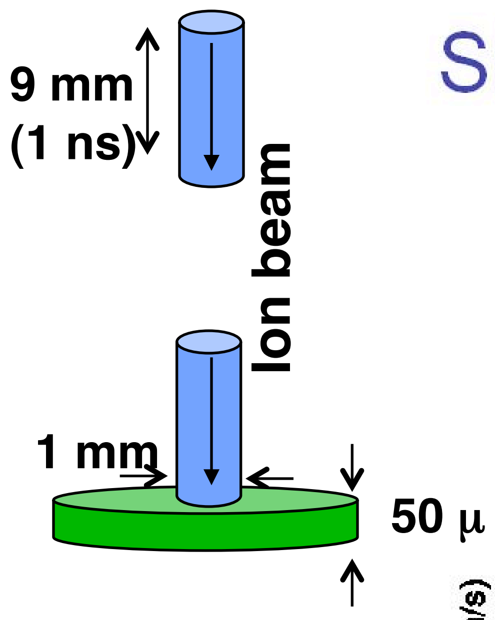


Shock positions at 18 and 20 ns for the 3 cases



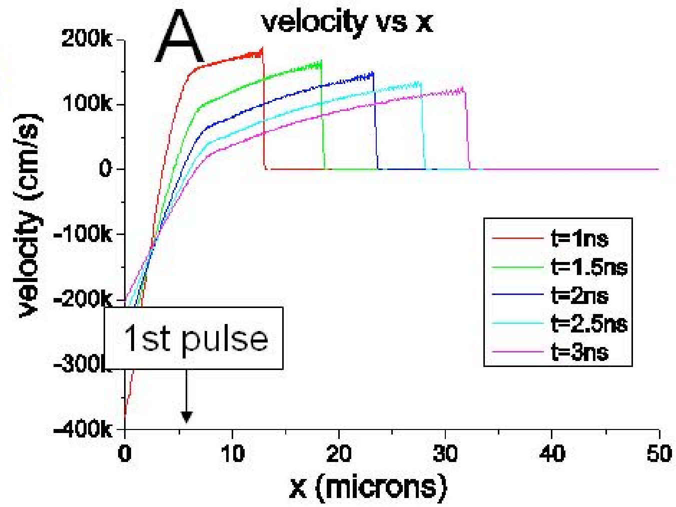
	1 ns	7 ns	9 ns
V_shock =	1.0 μ/ns	1.8 μ/ns	1.0 μ/ns
V_fluid =	0.9 μ/ns	1.6 μ/ns	0.9 μ/ns
ρ_fluid =	2.2 g/cm³	2.2 g/cm³	2.2 g/cm³

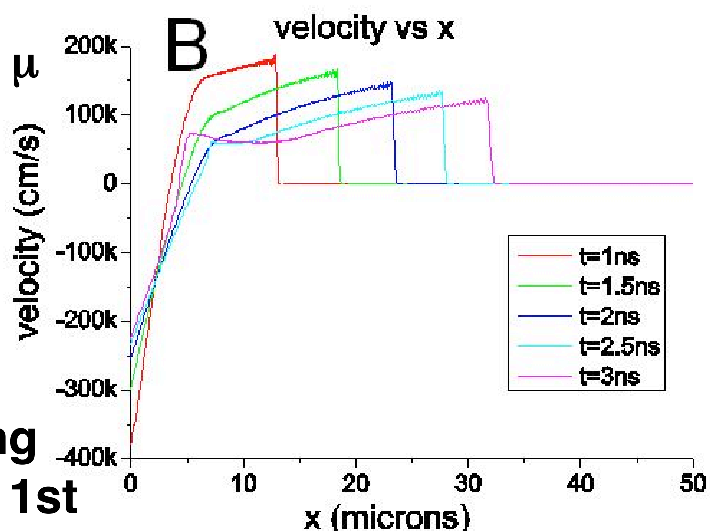
Simulations using DISH (using van der waals eos) confirm benefits of double pulsing

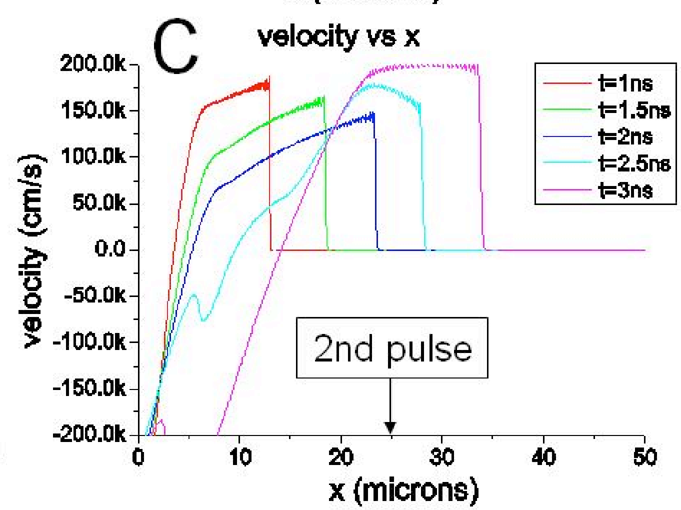


Simulation Results

Case	E_1	E_2
A	1 MeV	0 MeV
B	1 MeV	1 MeV
C	1 MeV	6 MeV

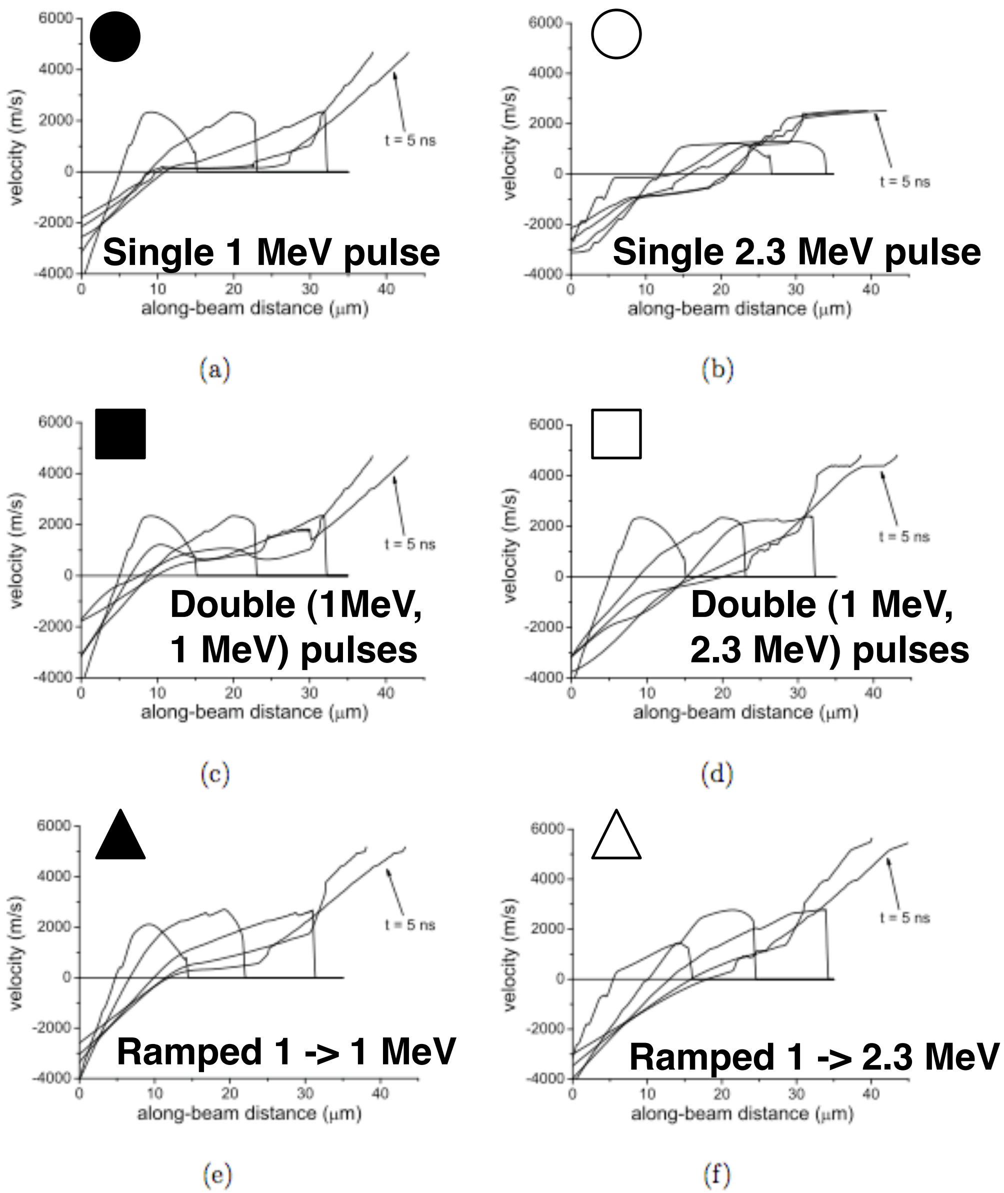




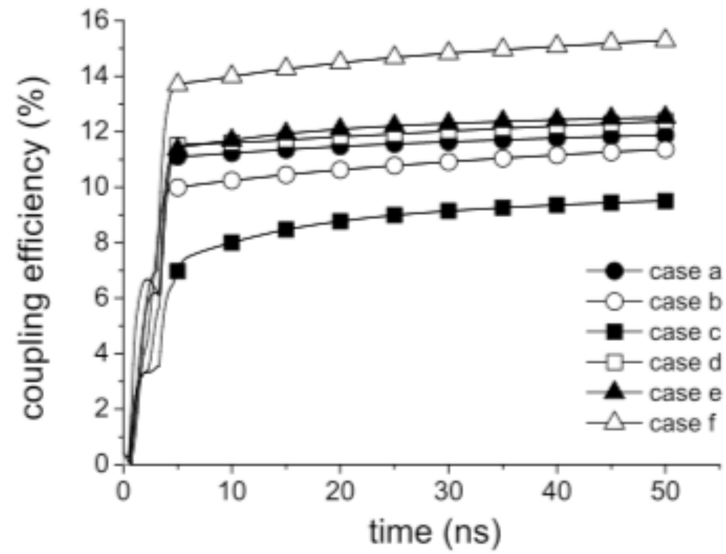


Ion: Li^{+} or Li^{++}
Target: **Solid Ar**
Intensity: 30 J/cm2 (each pulse)
Each pulse: 1 ns long
2nd pulse, 1ns after 1st
Simulations by Siu Fai Ng

Double or ramped pulse experiments could investigate variable range energy deposition



DISH simulations by S-F Ng

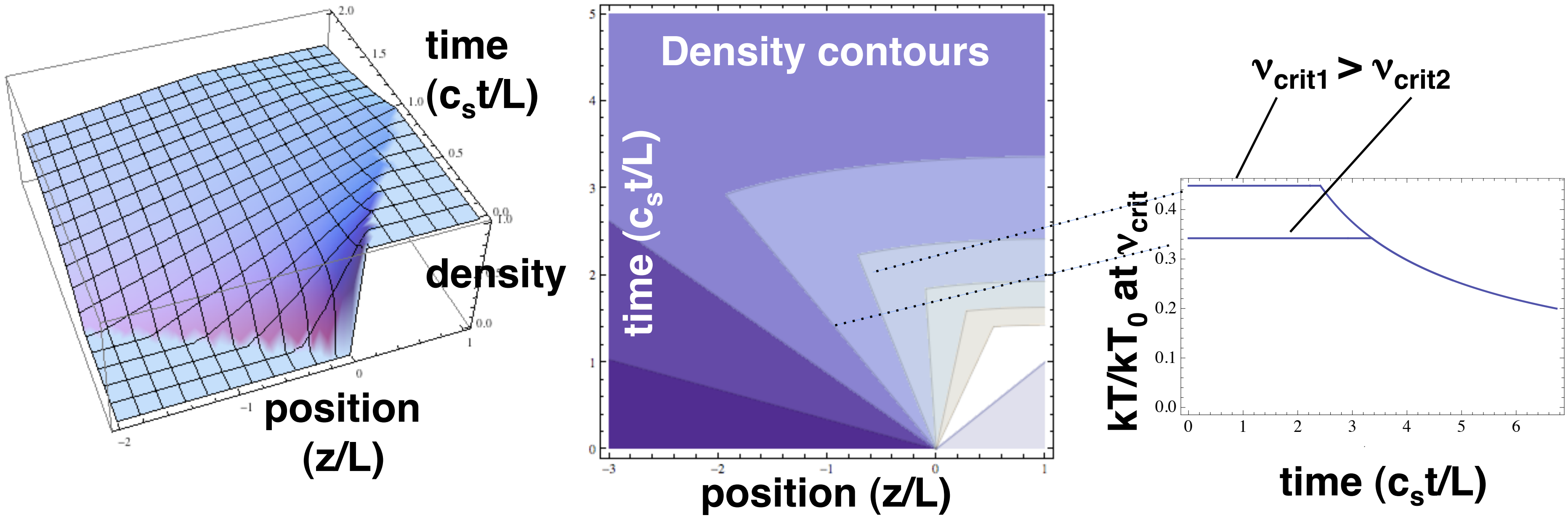


Energy swing between 1 MeV to 2.3 MeV shows detectable benefit of time dependent range

Intensity measurements at multiple frequencies can discriminate different EOS' used for hydro calculations

Critical frequency ν_{crit} defines "over dense" point where wave propagation becomes evanescent: $h\nu_{crit} = h\omega_p / 2\pi = 28 \text{ eV} \sqrt{\rho(\text{g/cm}^3) Z^* / A_{target}}$

Consider idealized case: Energy instantaneously deposited in slab 2L thick; ideal gas; Z* = constant



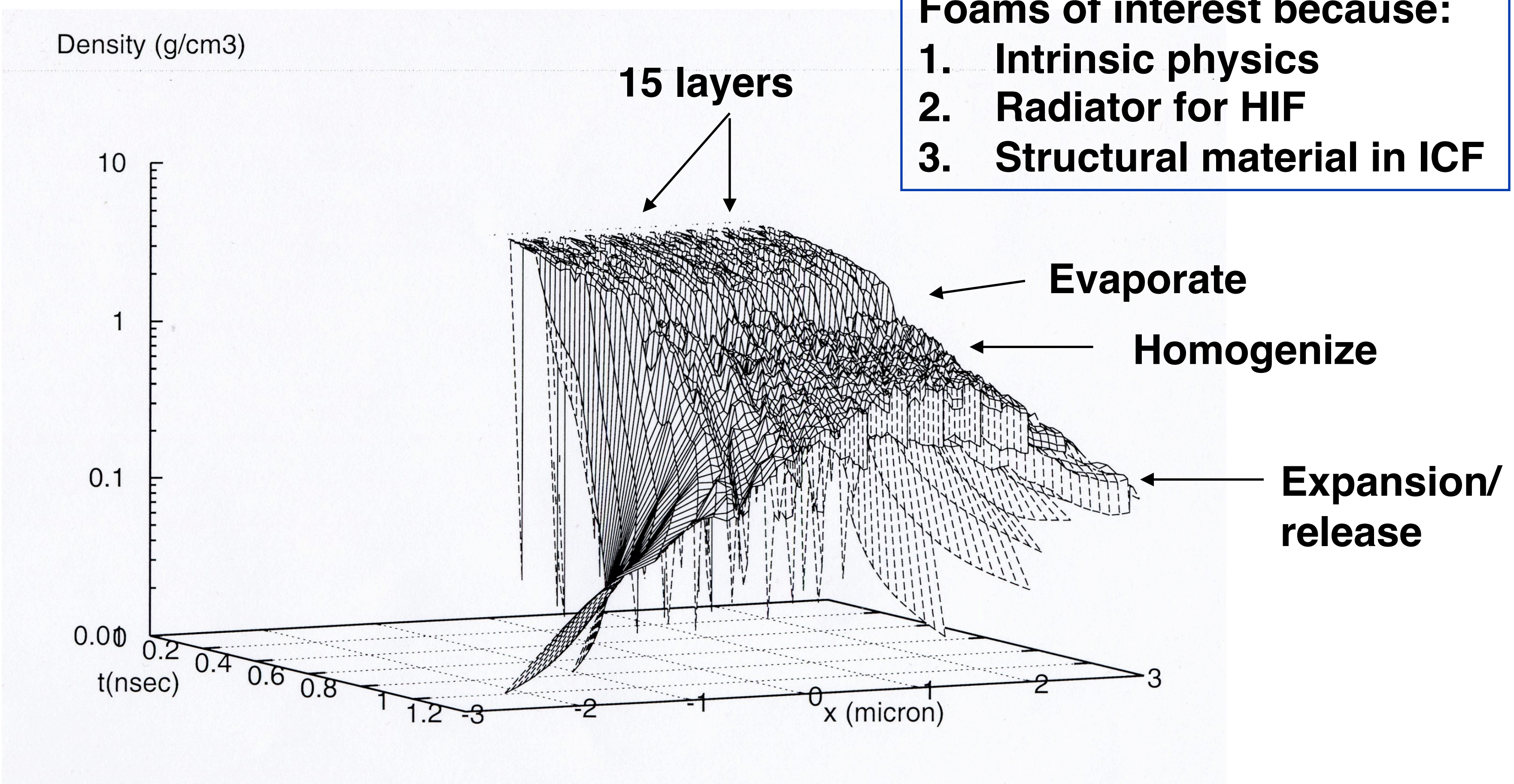
For adiabatic evolution lines of constant density coincide with lines of constant temperature (since $T \sim \rho^{\gamma-1}$). So higher frequencies will have shorter flattop pulse durations and sample higher temperatures.

Foams have been modeled as layers of solid separated by layers of void

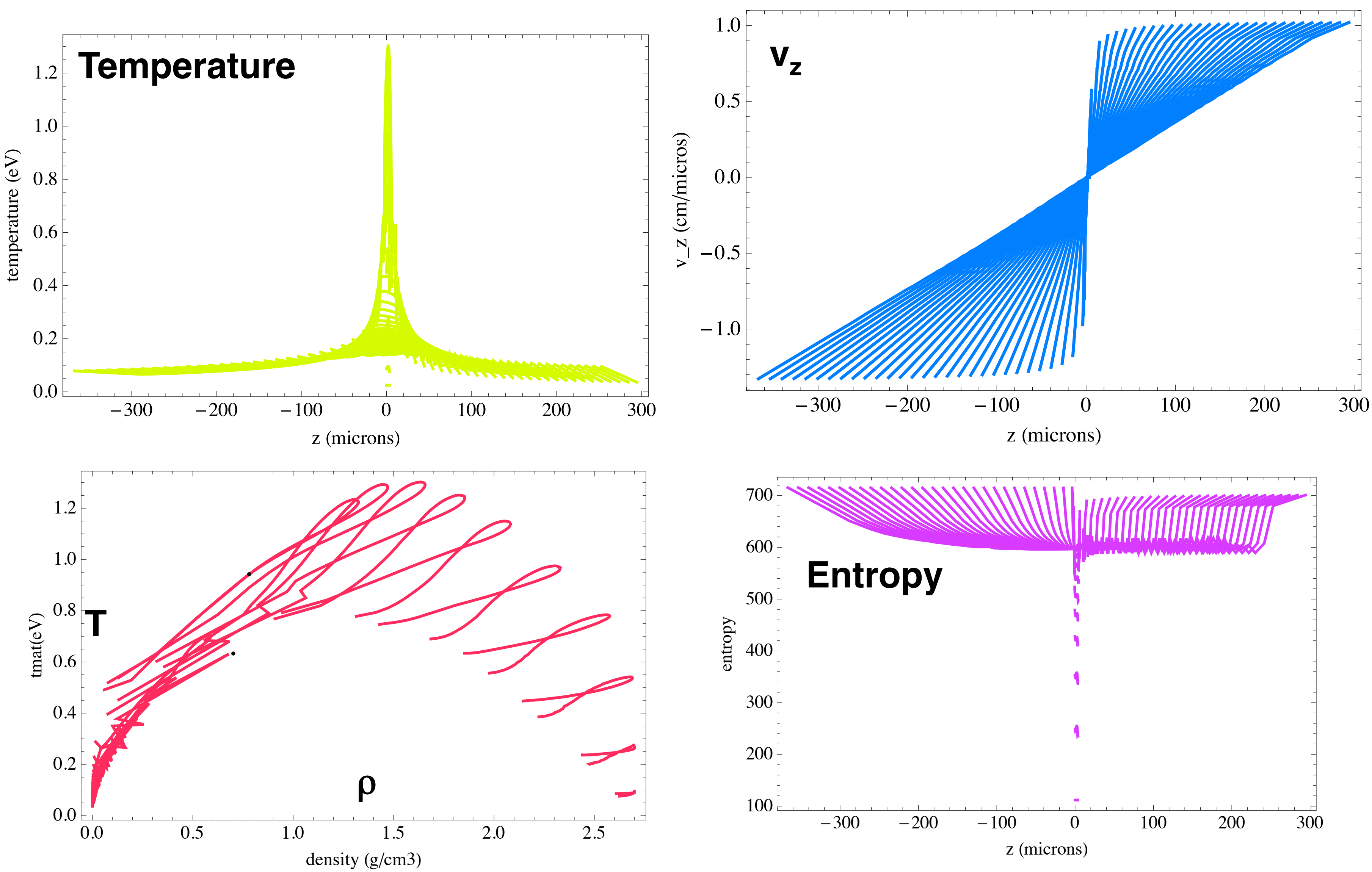
Codes used on foam modeling include: DPC (Saha based EOS), HYDRA (using QEOS), and DISH (using van der Waals EOS)

Foams of interest because:

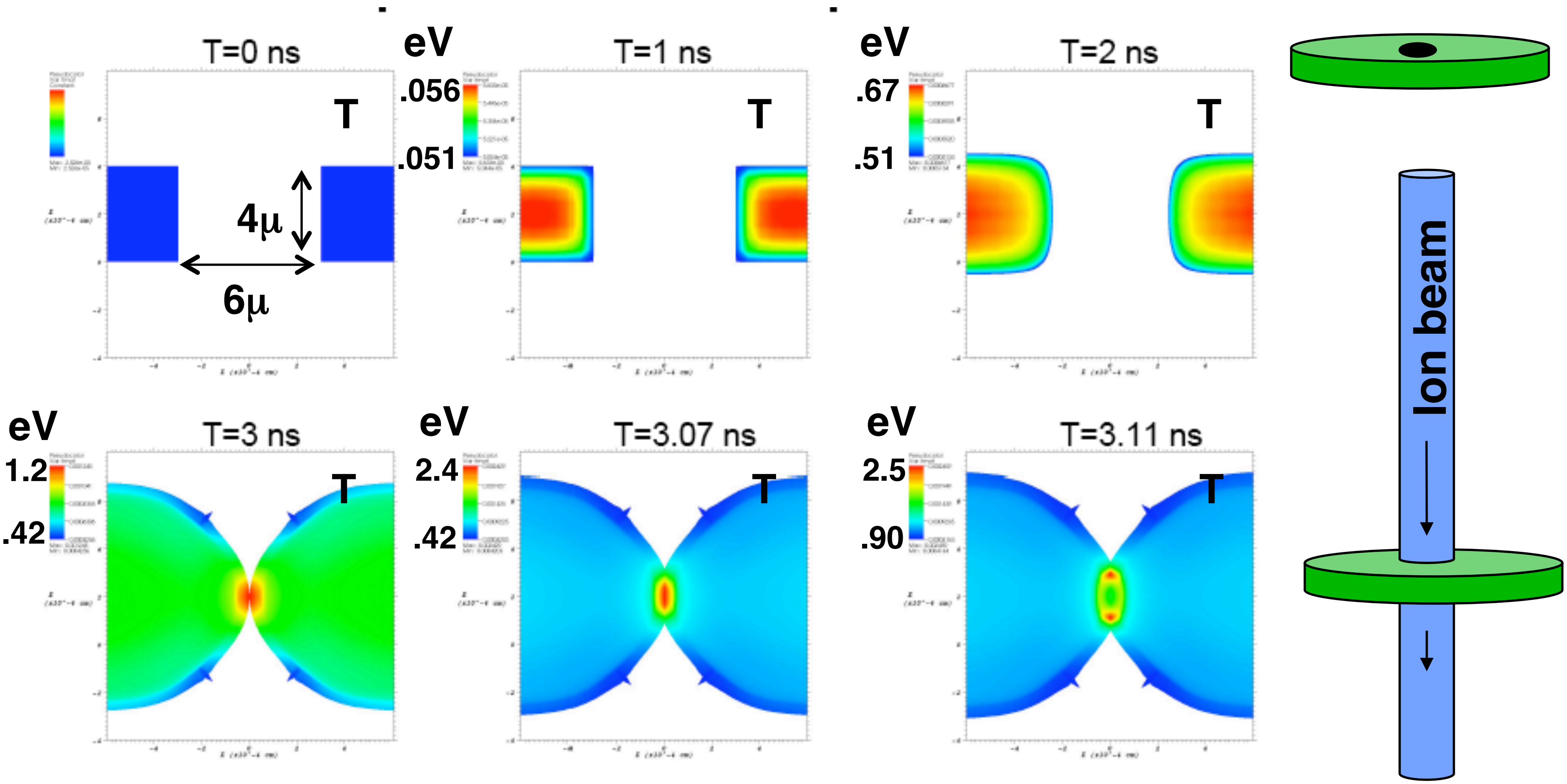
1. **Intrinsic physics**
2. **Radiator for HIF**
3. **Structural material in ICF**



Target evolution was tracked for 30 ns

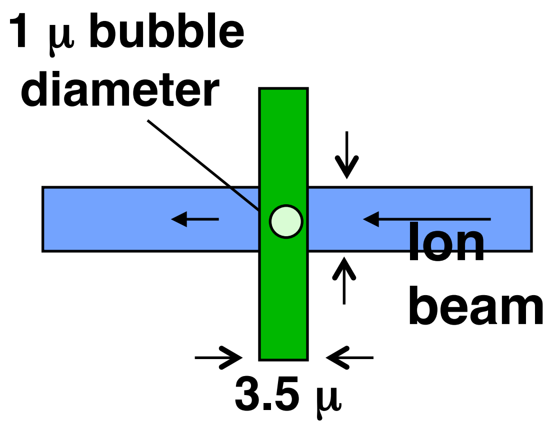


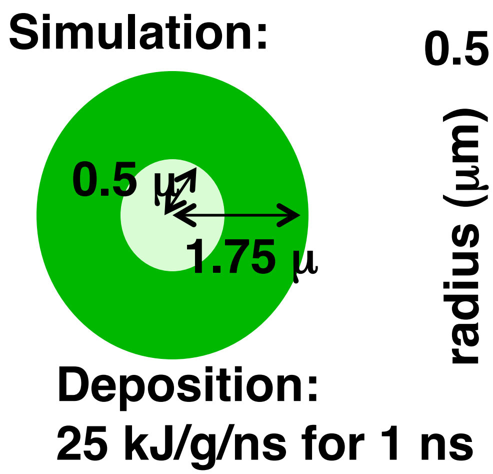
A cylindrical hole can create regions of temperature and pressure larger than in a simple foil

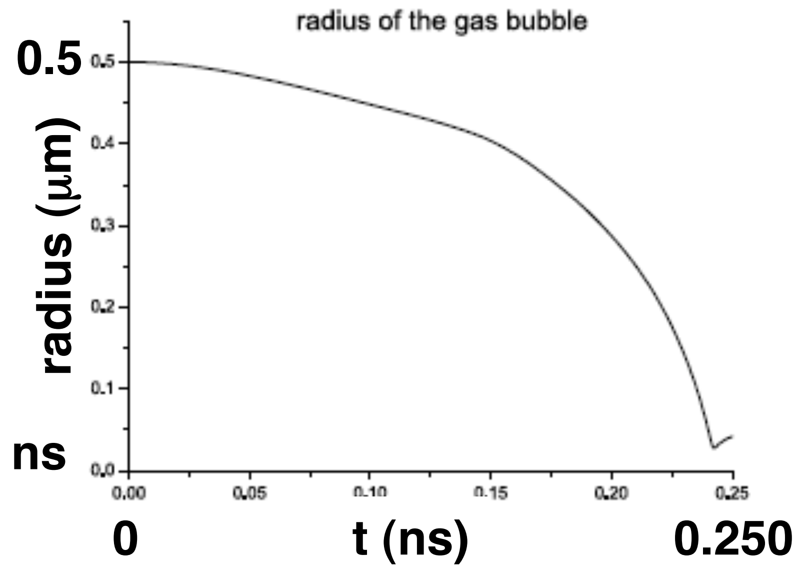


HYDRA simulations by E. Henestroza (using LEOS).
Solid Tin target. 2.8 MeV Li^+, 10 J/cm^2 assumed.
T_{max} = 2.6 eV; P_{max} = 1.3 Mbar ρ_{max}= 11 g/cm^3 (ρ_{init}= 7 g/cm^3); v_{imp} = 3.5 km/s
Advantage: relatively easy to manufacture and diagnose

If instead of a cylindrical hole, a spherical void is placed in the foil, higher pressures are possible

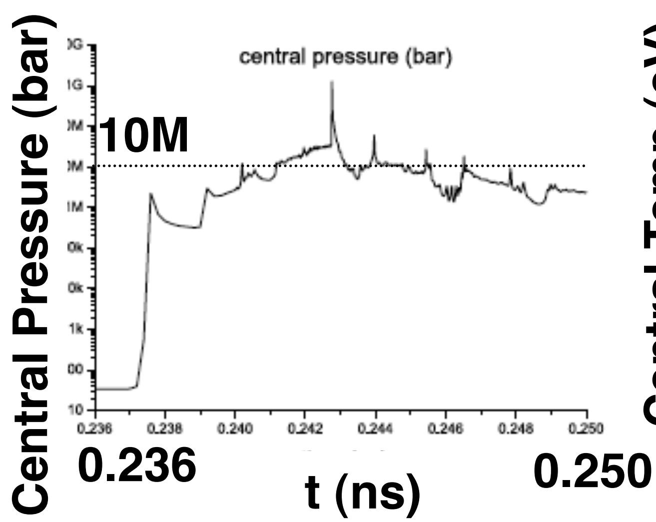


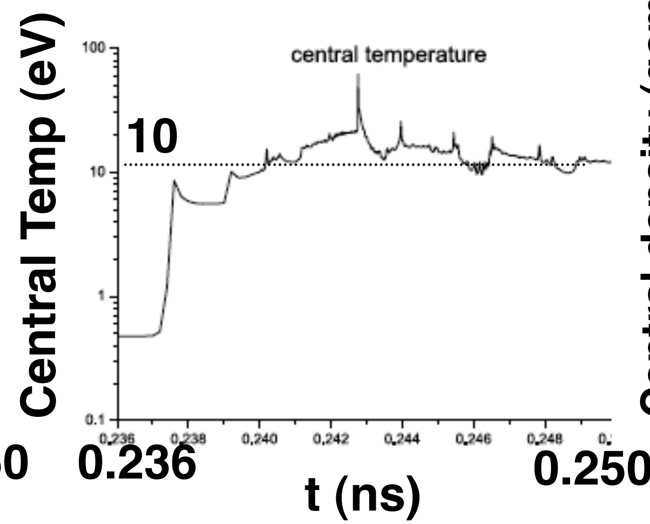


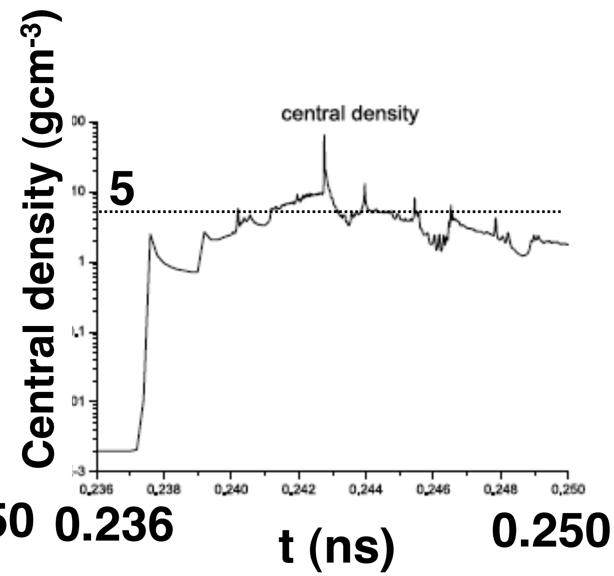


Simulations by Siu-Fai Ng
(using DISHr, QEOS)

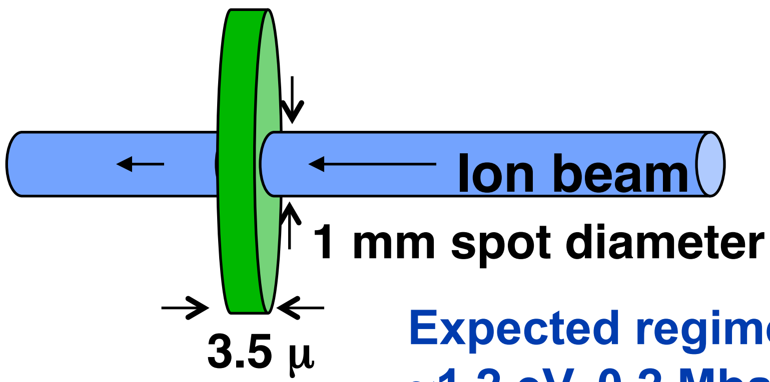
P_{max} > 10 Mbar, T_{max} > 10 eV, ρ_{max} > 5 g/cm³





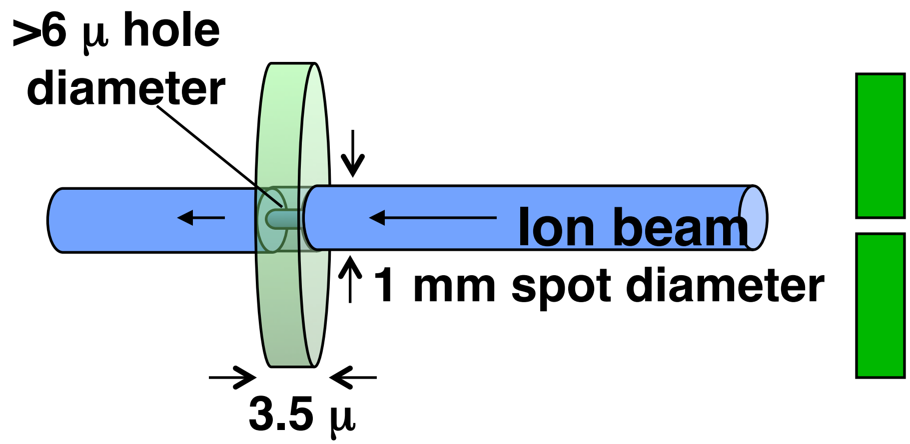


Several target options have been considered for WDM studies on NDCX II

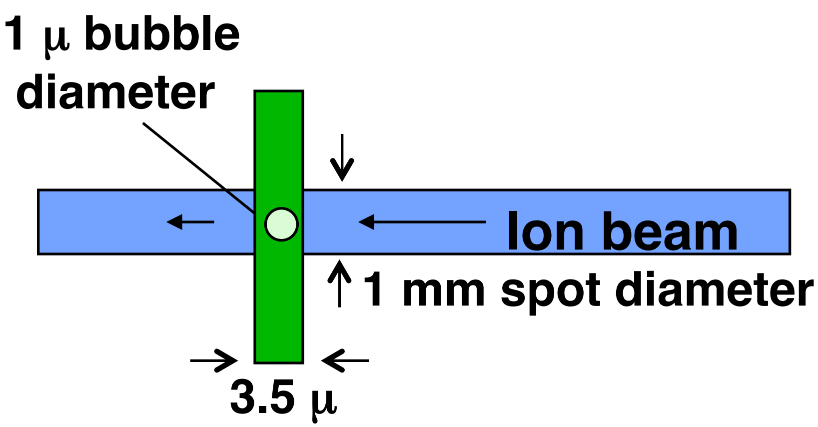


Expected regime:
~1.2 eV, 0.2 Mbar

Solid planar targets

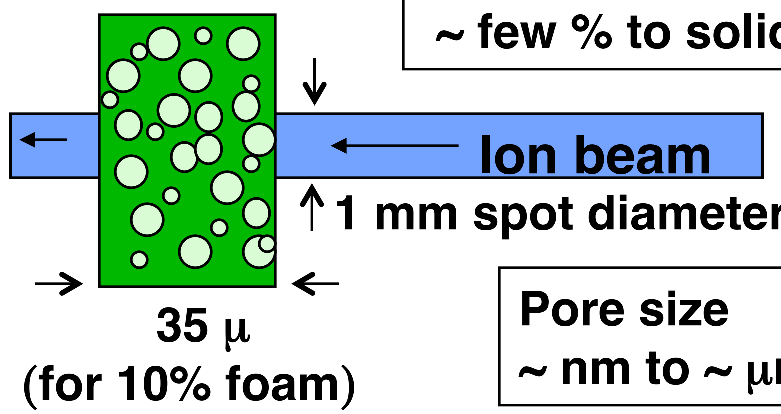


Cylindrical "bubble" targets



Spherical bubble targets

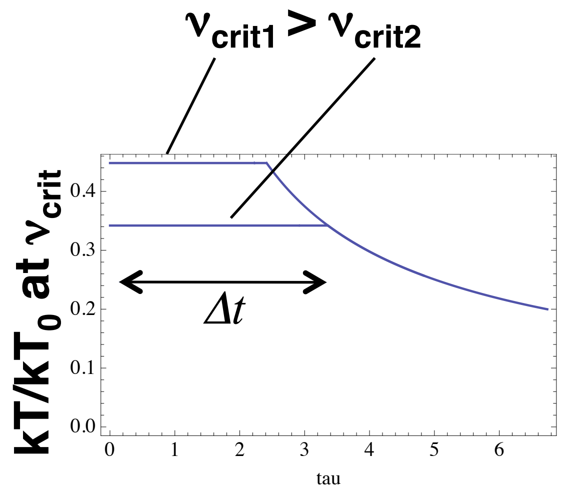
Foam densities
~ few % to solid



Pore size
~ nm to ~ μm

Foam planar targets

Observed pulse width Δt can be significantly larger than hydrodynamic time at lower observation frequencies



$$\frac{\rho_{center}}{\rho_0} = \frac{3}{2}\left(1 - \frac{1}{\tau^{1/2}} + \frac{1}{3\tau} - \frac{1}{3\tau^{3/2}}\right)/(3\tau - 4\tau^{1/2} + 1) \qquad \text{for} \quad \tau > 1$$

$$\frac{\rho_{center}}{\rho_0} \cong \frac{1}{2\tau} \qquad \text{for} \quad \tau >> 1$$

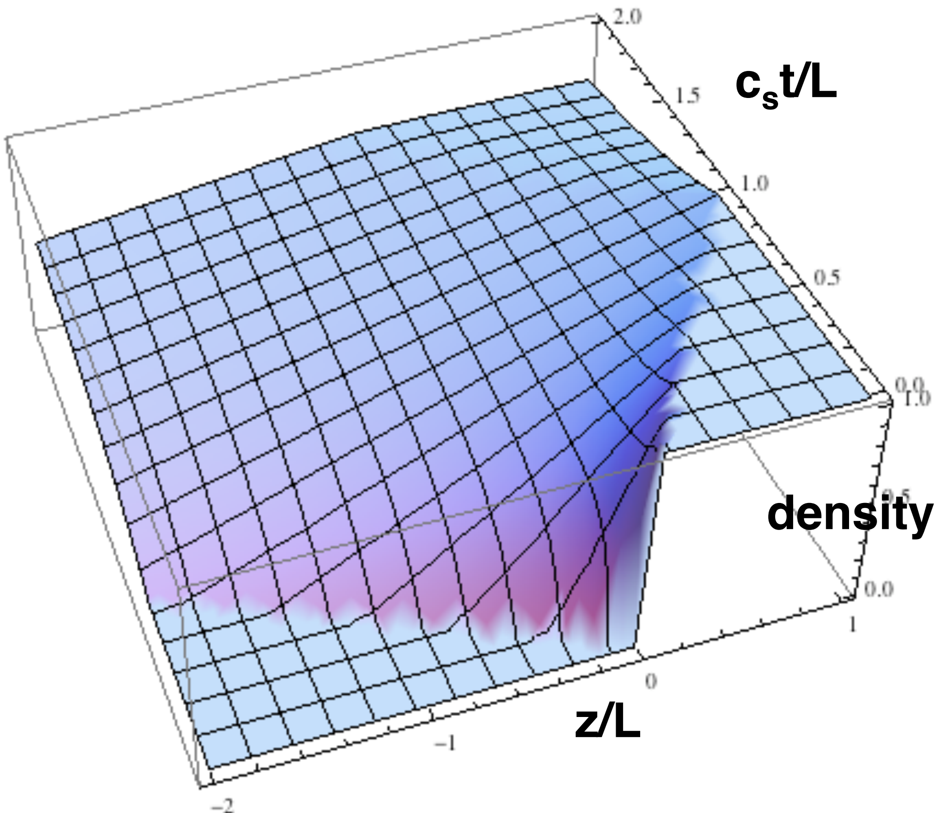
$$\nu_{crit} \sim (\rho Z^*)^{1/2} \qquad \rightarrow \qquad \Delta t \sim (L/c_s)\ \nu_{crit0}{}^2 Z^{*2} / (2\ \nu_{crit}{}^2 Z_0{}^{*2}),$$

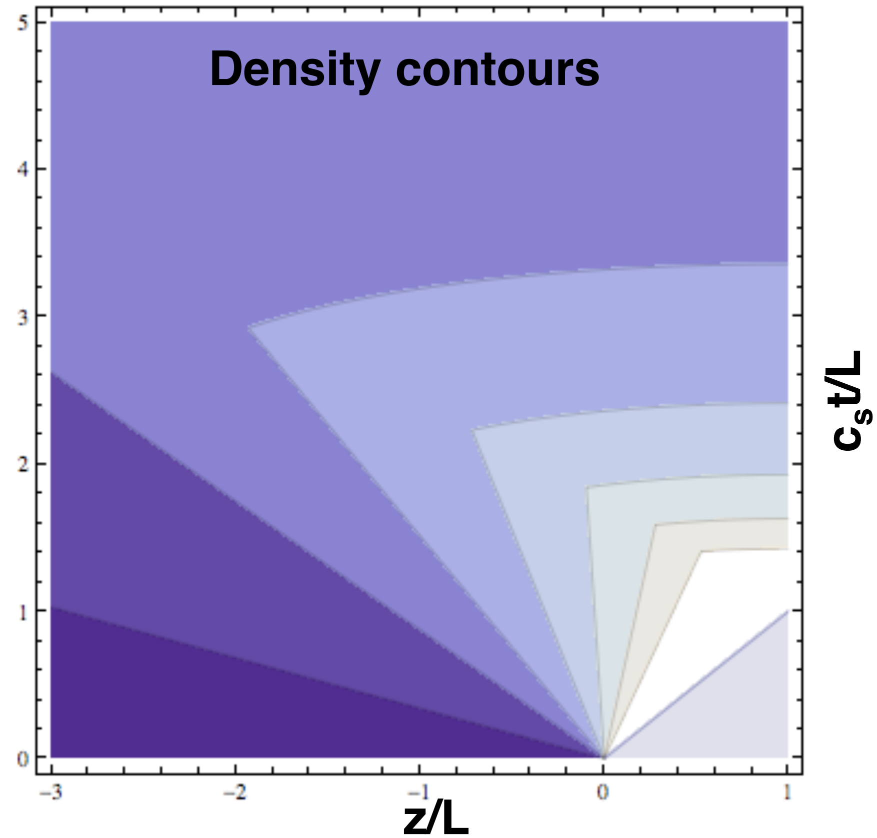
$$T/T_0 = (\rho/\rho_0)^{2/3} = (\nu_{crit} Z_0{}^* / [\ \nu_{crit0} Z^*])^{4/3}$$

Critical frequency ν_{crit} defines "over dense" point where wave propagation becomes evanescent

$$h\nu_{crit} = h\omega_p / 2\pi = 28 \text{ eV} \sqrt{\rho(\text{g/cm}^3) Z^* / A_{\text{target}}}$$

Consider idealized case: Energy instantaneously deposited; ideal gas; Z* = constant

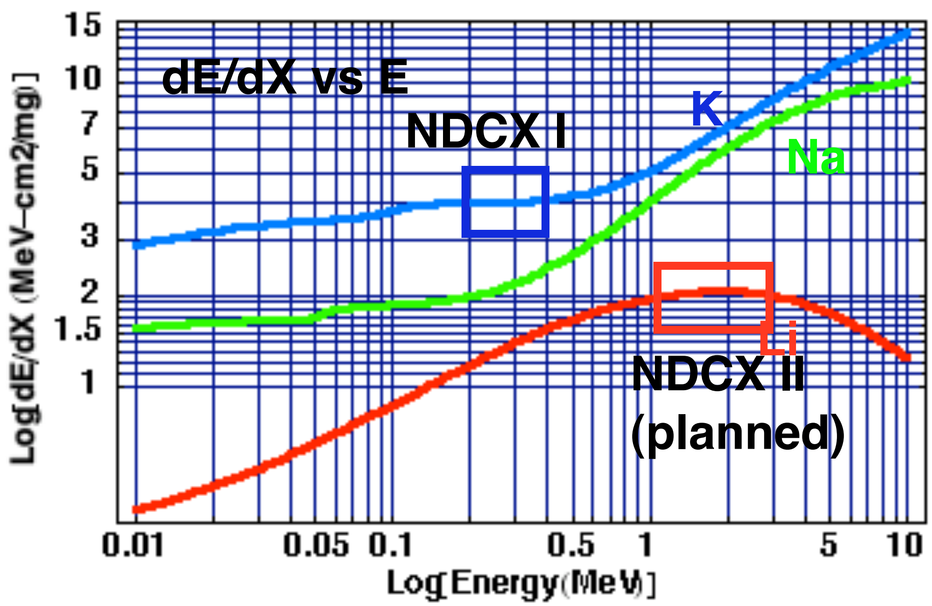




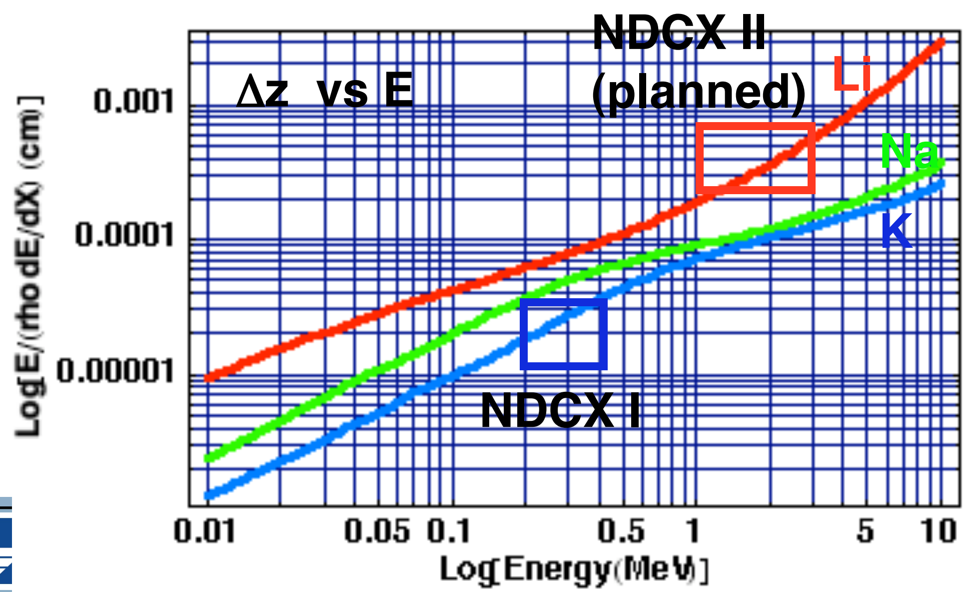
For adiabatic evolution lines of constant density coincide with lines of constant temperature (since $T \sim \rho^{\gamma-1}$).

Temperature uniformity is achieved by choosing ion deposition region where d(dE/dX)/dE ≈ 0

SRIM code results gives dE/dX for three ions of interest (K, Na, and Li).

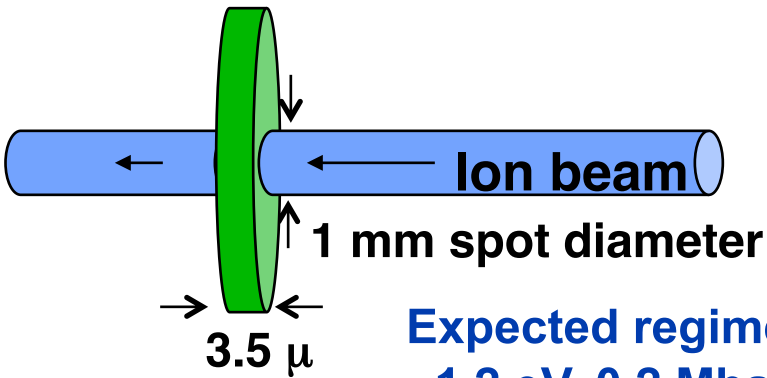


Li ions at ~ 1.8 MeV are at Bragg peak (although K ions at 200 - 400 keV are near inflection point)



Also range of Li ions at ~ 1.8 MeV is ~ 3 μ (a factor of 10 times longer than 400 keV K ions) so hydro time is factor of 10 longer

The nominal beam assumes a 30 J/cm² 2.8 MeV Li ion beam, corresponding to 20 kJ/g in Al (SRIM)



Expected regime:
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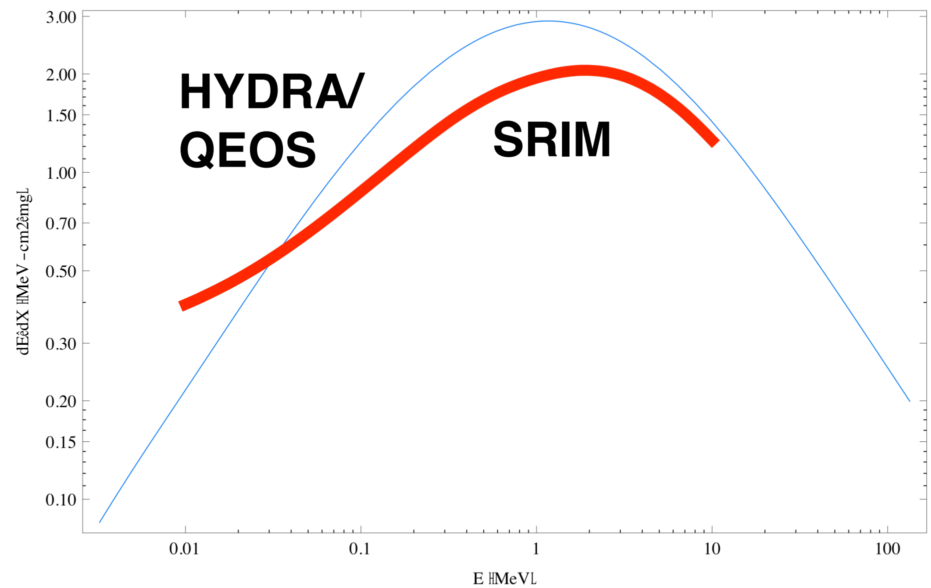
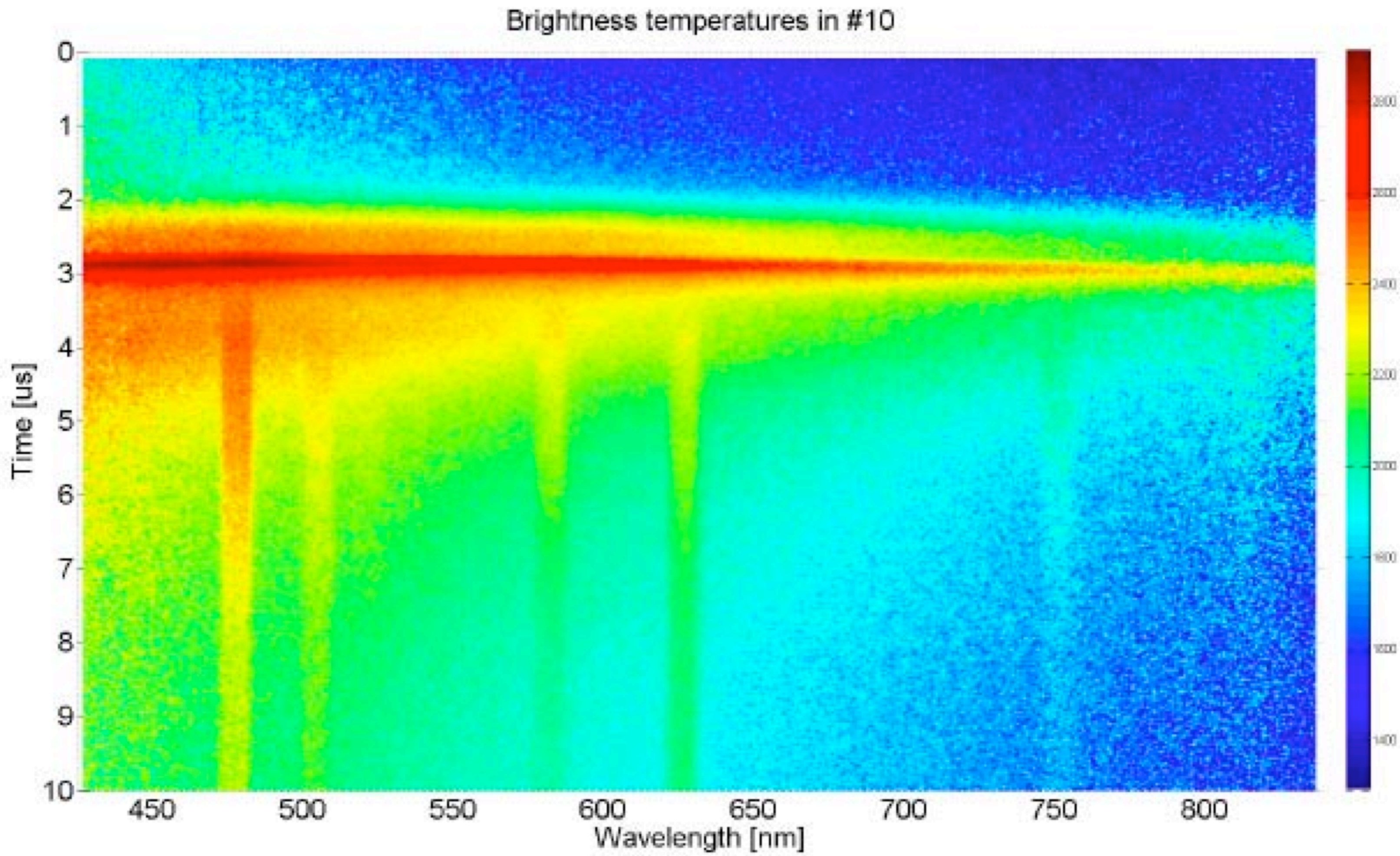
Solid planar targets



For HYDRA[1] runs we assume the nominal beam results in 20 kJ/g in Al. This implies the simulated beam had a fluence of 20 J/cm² (instead of 30 J/cm²)

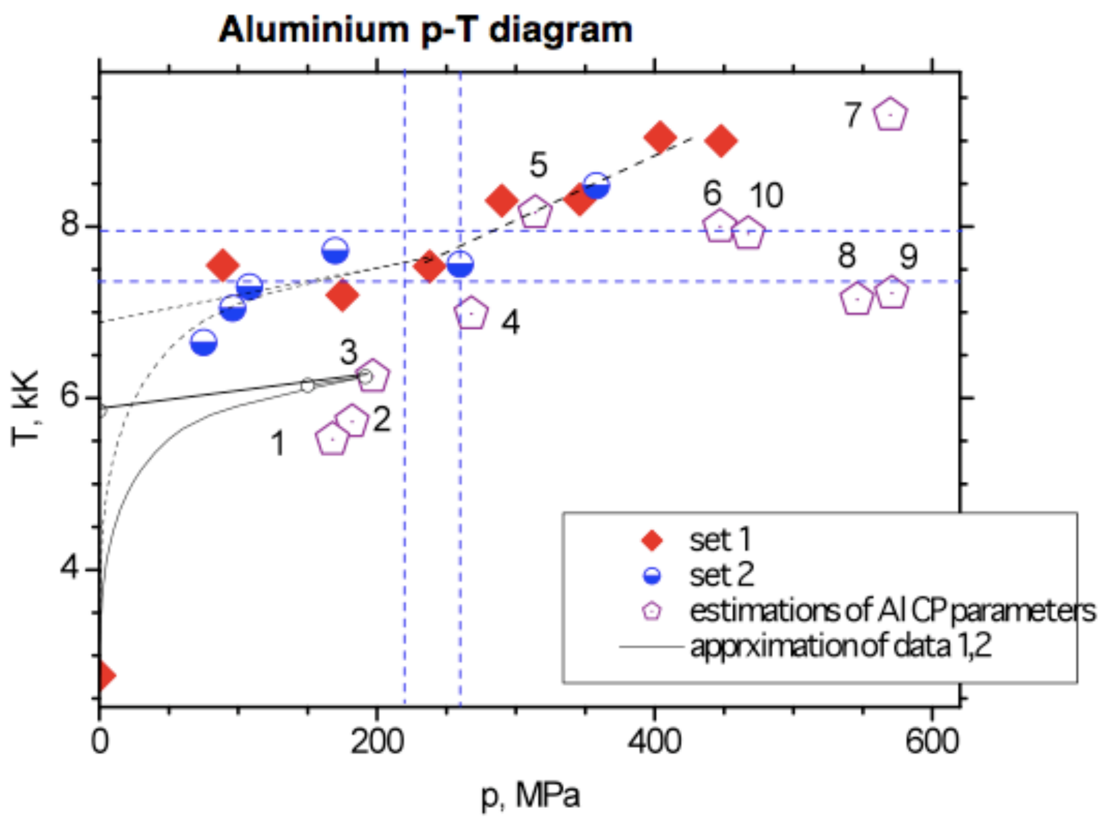
1. M. M. Marinak, G. D. Kerbel, N. A. Gentile, O. Jones, D. Munro, S. Pollaine, T. R. Dittrich, and S. W. Haan, Phys. Plasmas 8, 2275 (2001).

Typical data in foil targets shows heating from the prepulse and compressed pulse on NDCX I



Streak-spectrometer data in Au target showing transition from continuum emission to emission lines from heated gold

Theories and experiments place critical point between 5500 K and 11000 K (0.47 eV and 0.945 eV)



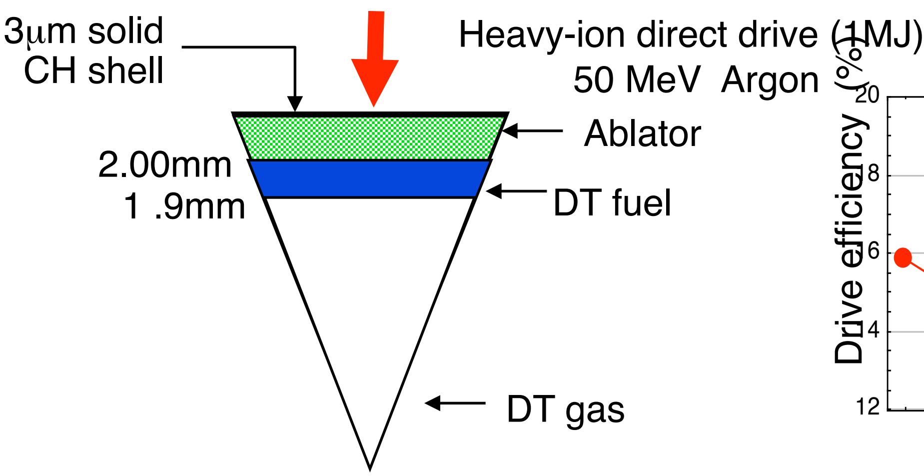
From presentation by Dmitry Nikolaev July 6, 2009, LBNL

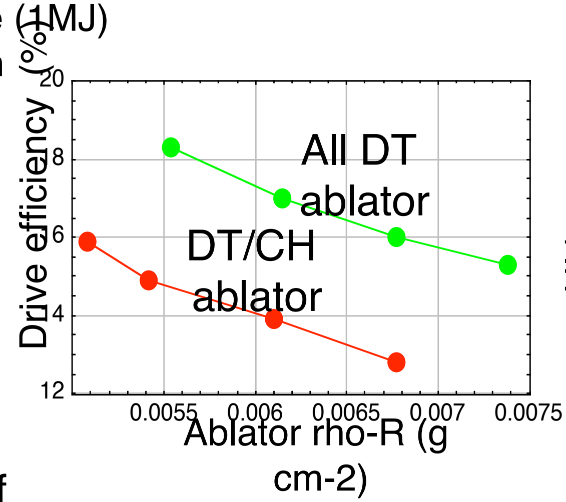
	authors	p, MPa	T, K
1	Young, Corey 1995	168	5520
2	Gathers 1986	182	5726
3	Lomonosov 2007	197	6250
4	Levashov 2000	268	8160

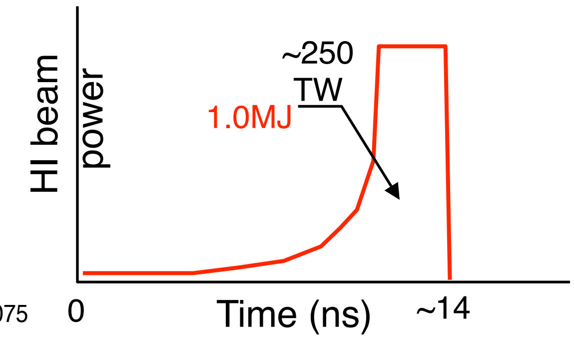
	authors	p, MPa	T, K
6	Fortov, Dremin, Leont'yev 1975	447	8000
7	Likal'ter 1985	570	9300
8	Young, Alder 1971	546	7151
9	Bushman 1989	571	7222
10	Gordeev et.al 2008	467	7917
	This work	240 ± 20	7650 ± 300

Heavy-ion direct drive LASNEX runs by John Perkins found gains ≥ 50 at 1MJ with high coupling efficiency (15%).

Coupling efficiency ≡ fuel shell kinetic energy/ion beam energy





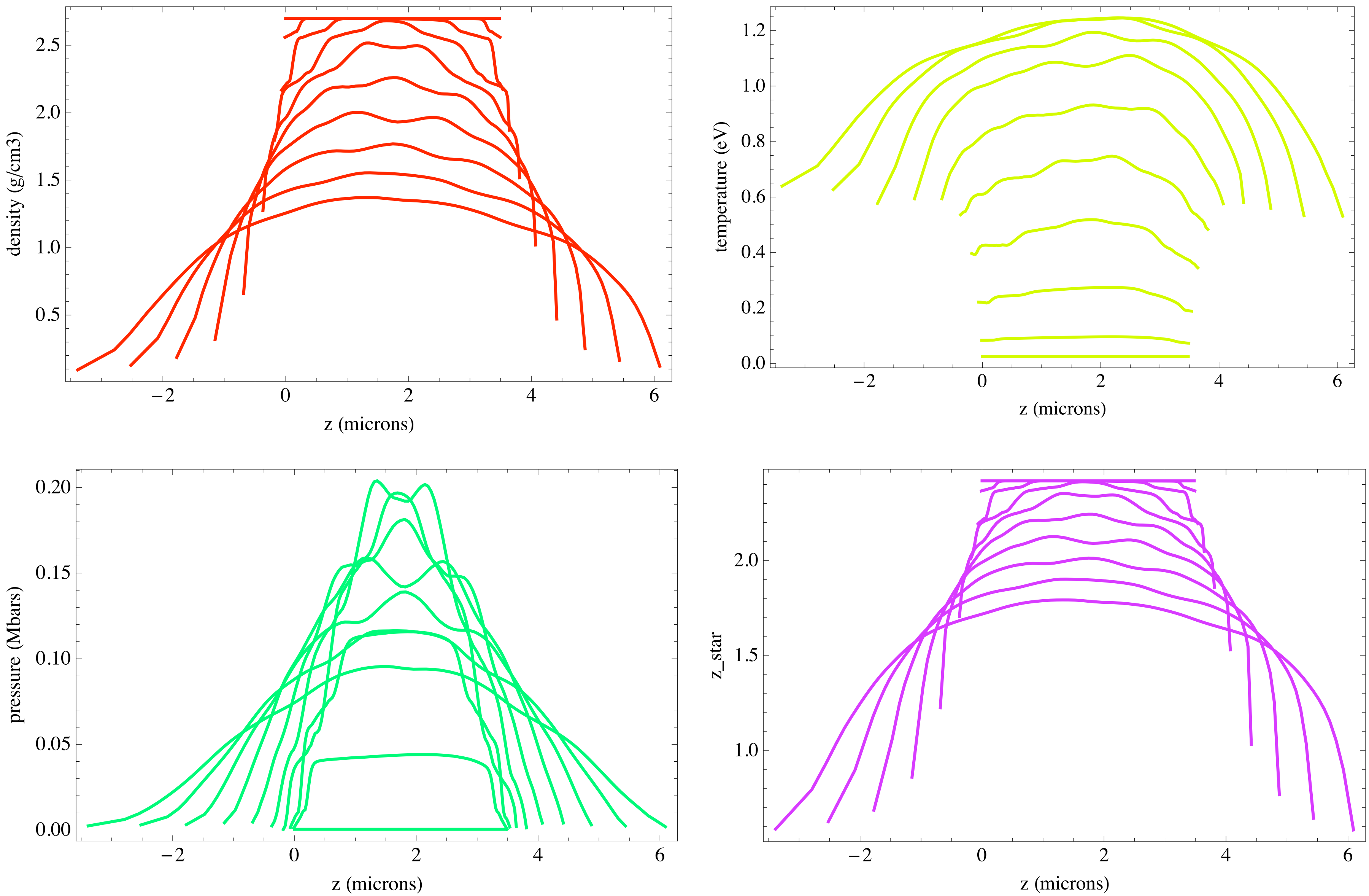


(See Logan, Perkins, Barnard, Phys. of Plasmas, **15**, 07271, 2008).

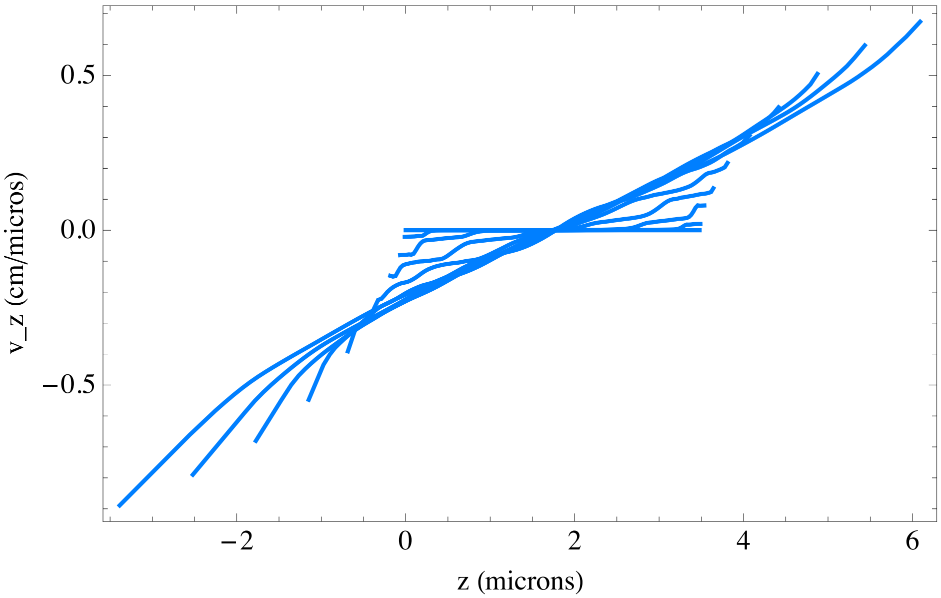
Higher efficiencies and gains may be possible by using energy ramp

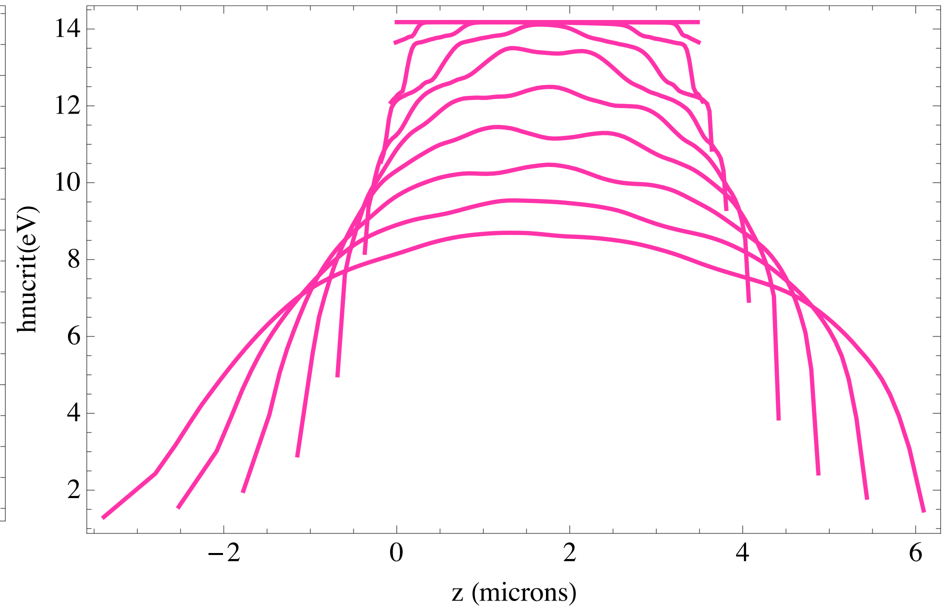
	Coupling efficiency	Target gain (at 1MJ drive)
Laser Indirect Drive	**~ 2-4%**	**~ 10**
Laser Direct Drive	**~ 5-8%**	**~ 25**
Heavy ion direct drive with energy ramp	**~ 25%**	**~ 100**

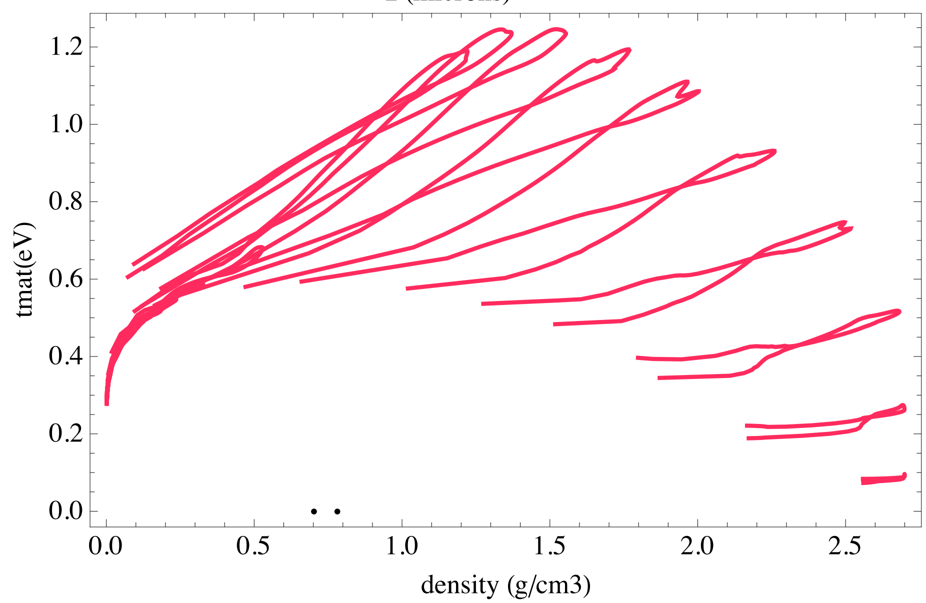
Evolution of center of 3.5 μ thick Al foil over the heating phase (1 ns) using LEOS with maxwell construction



Evolution of center of 3.5 μ thick Al foil over the heating phase (1 ns) using LEOS with maxwell construction

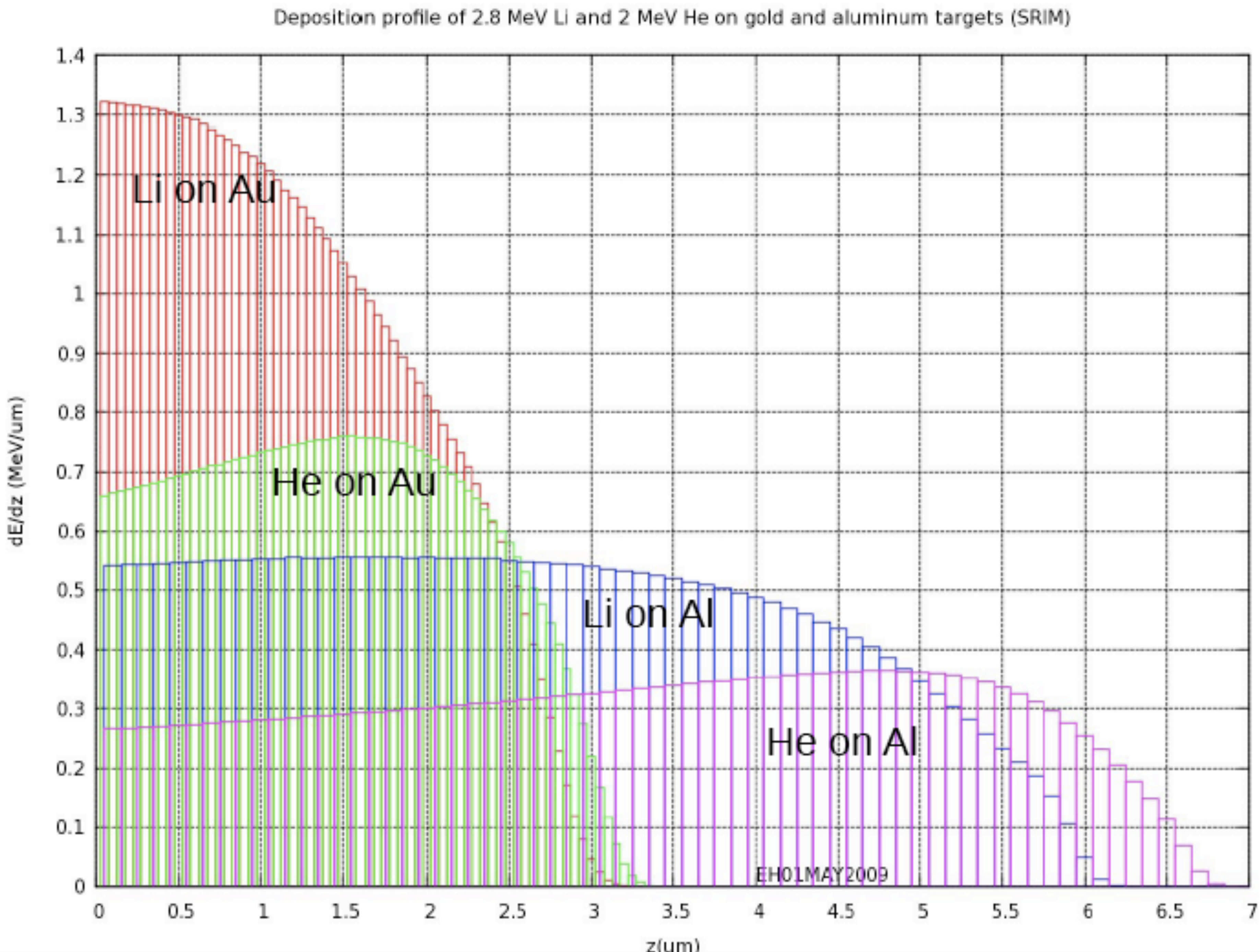






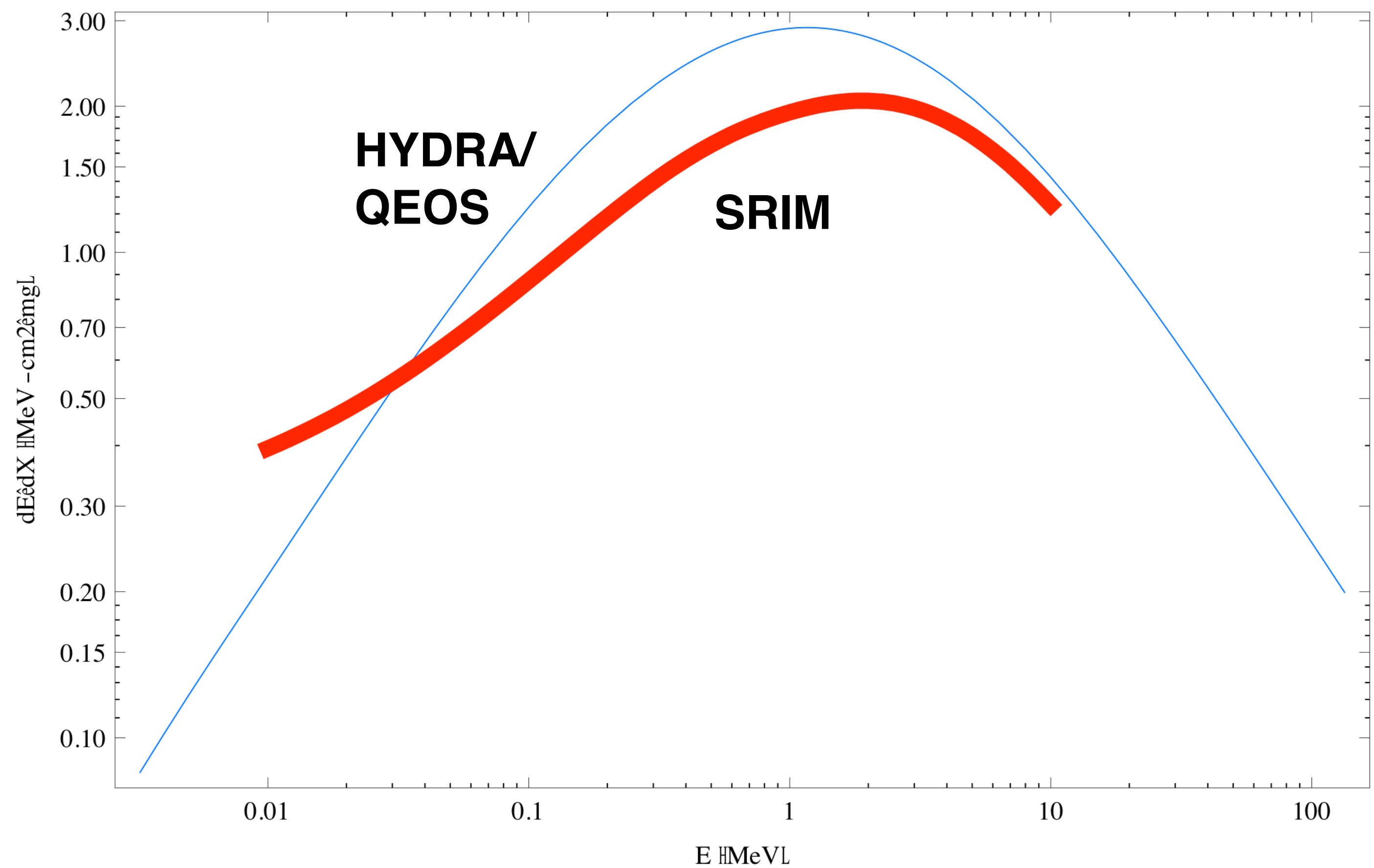
From Enrique Henestroza's NDCXII talk May13, 2009

Deposition profiles from TRIM



13MAY2009

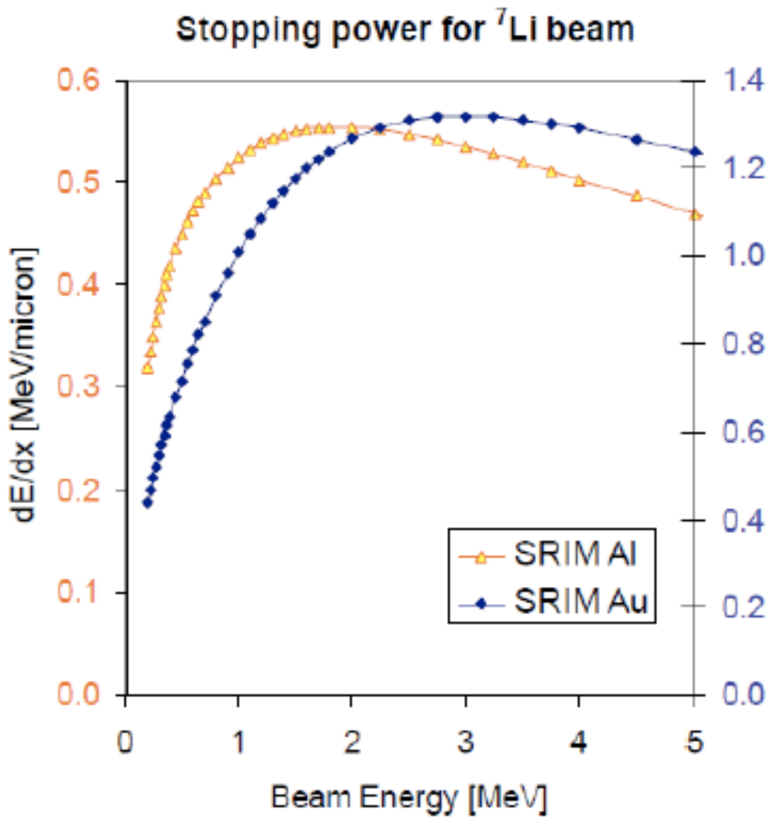
The nominal beam assumes a 30 J/cm^2 2.8 MeV Li ion beam, corresponding to 20 kJ/g in Al (SRIM)

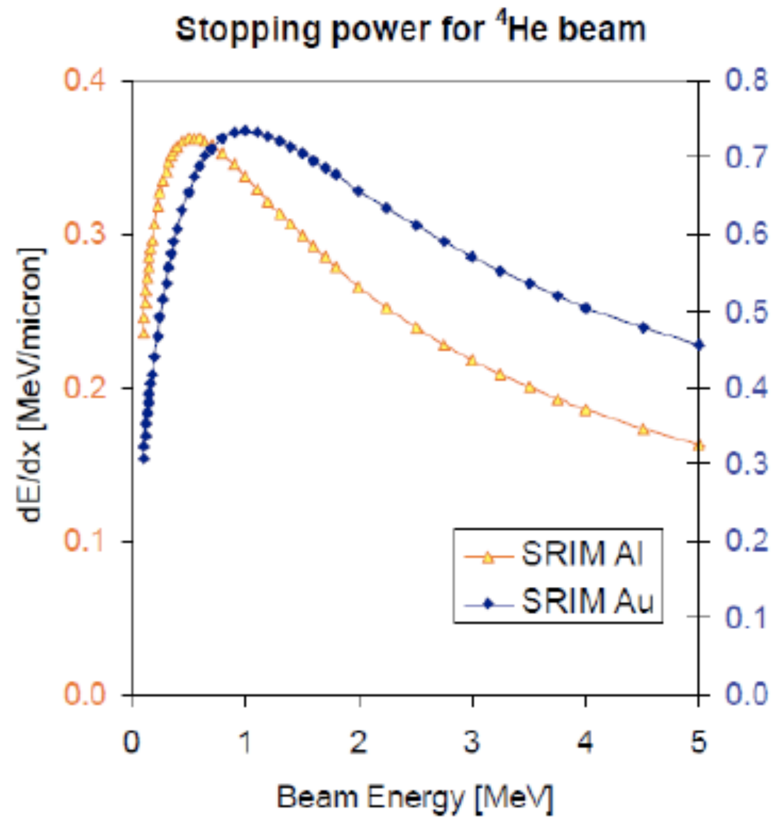


For HYDRA runs we assume the nominal beam results in 20 kJ/g in Al.
This implies the simulated beam had a fluence of 20 J/cm^2 (instead of 30 J/cm^2)

FROM FRANK'S PRESENTATION 5/12/2009

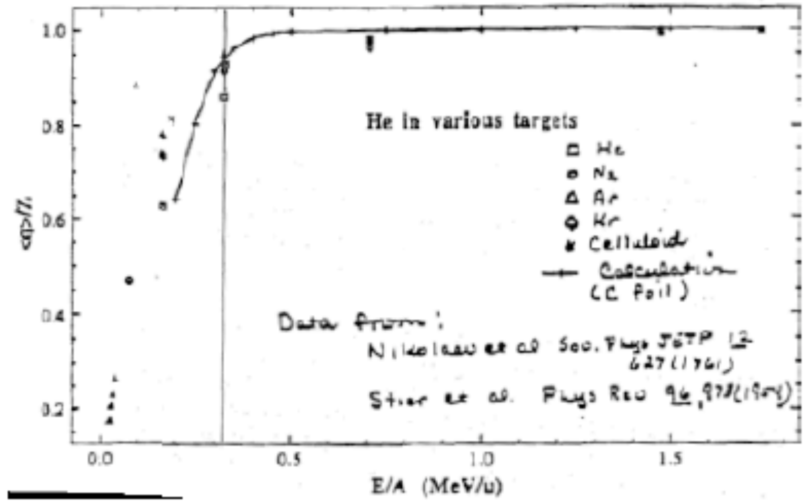
Comparison between Li and He stopping in target.



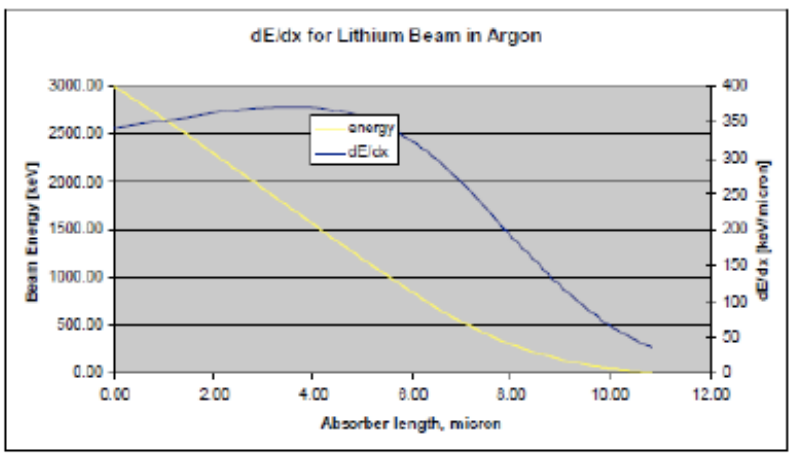


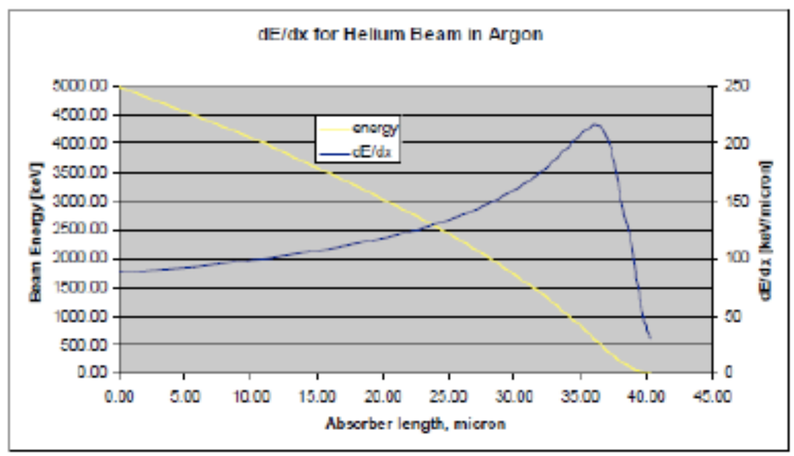
He vs Li.

- He source may have
  - Higher current density, but
  - higher emittance than Li
- Option exists to strip He^{+} to He^{++} at ~1 MeV
- He longer range by factor ~2-4
  - Reduced sensitivity to hydro expansion
  - Increased requirement for beam current

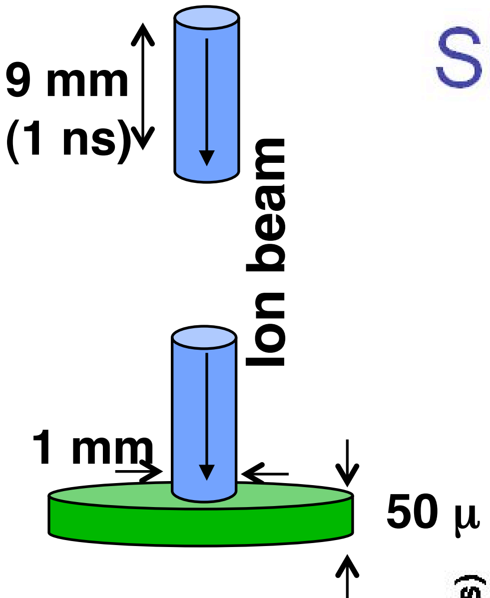


Martin Schulze, ca. 1991





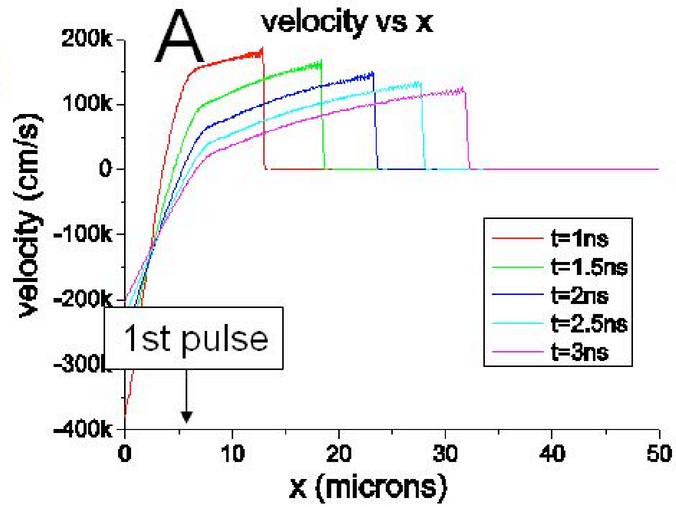
Simulations show that an NDCX II double pulse experiment could confirm benefits of double pulsing

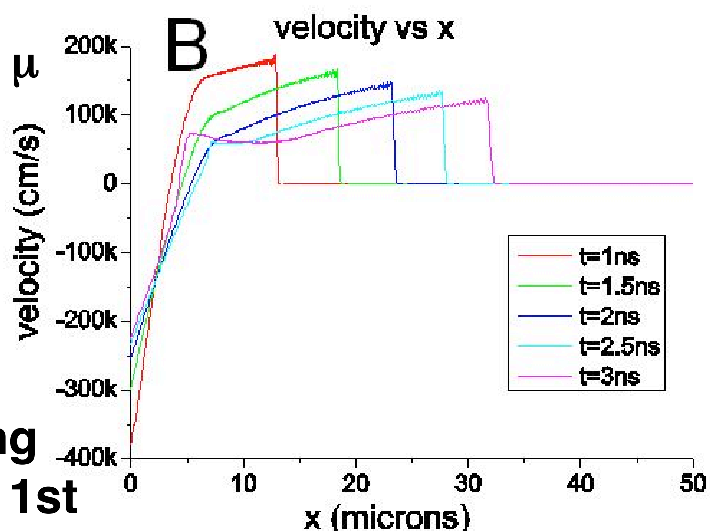


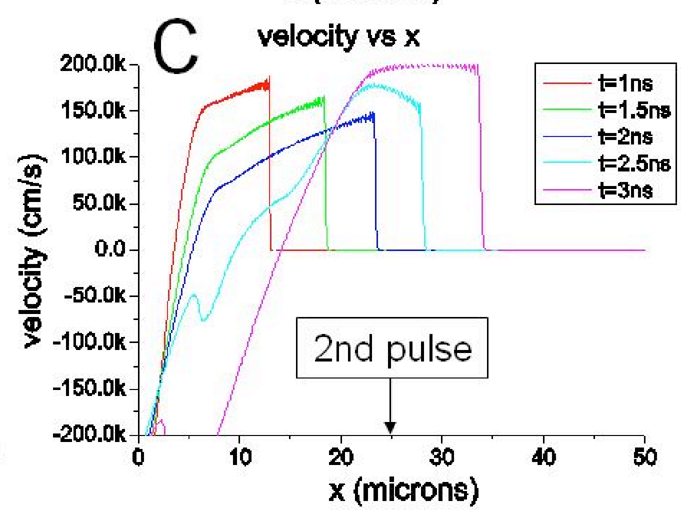
Ion: Li^{+} or Li^{++}
Target: Solid Ar
Intensity: 30 J/cm2 (each pulse)
Each pulse: 1 ns long
2nd pulse, 1ns after 1st
Simulations by Siu Fai Ng (DISH; vdw EOS)

Simulation Results

Case	E_1	E_2
A	1 MeV	0 MeV
B	1 MeV	1 MeV
C	1 MeV	6 MeV







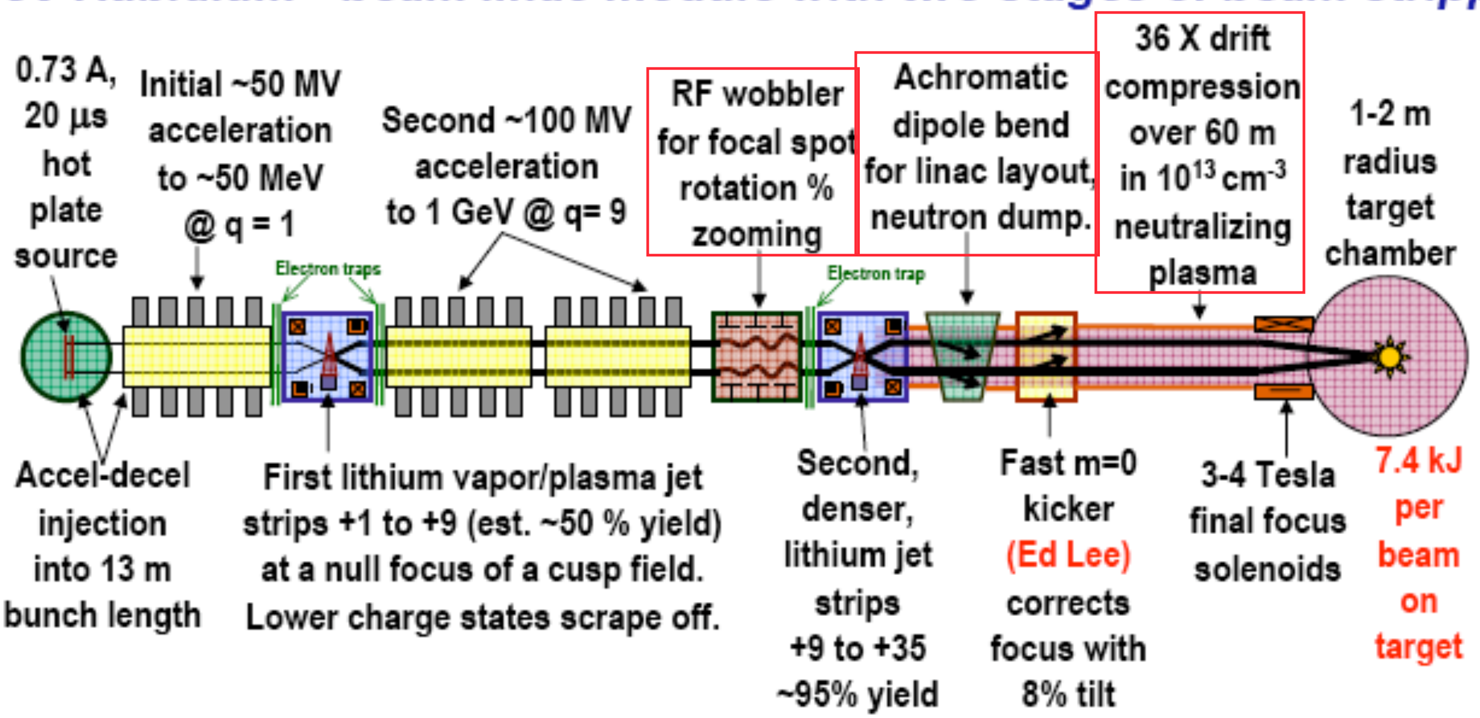
(simulations by Vietzer indicate room temp Al foam also candidate)

In addition to target physics, NDCX II will serve as a platform for driver beam physics tests

- RF Wobbler dynamics
- beam bending
- beam-plasma interactions
- unneutralized acceleration with bunch compression
- neutralized bunch compression and final focus

Example of one module of driver:

1 GeV Rubidium^{+9} beam linac module with two stages of beam stripping.

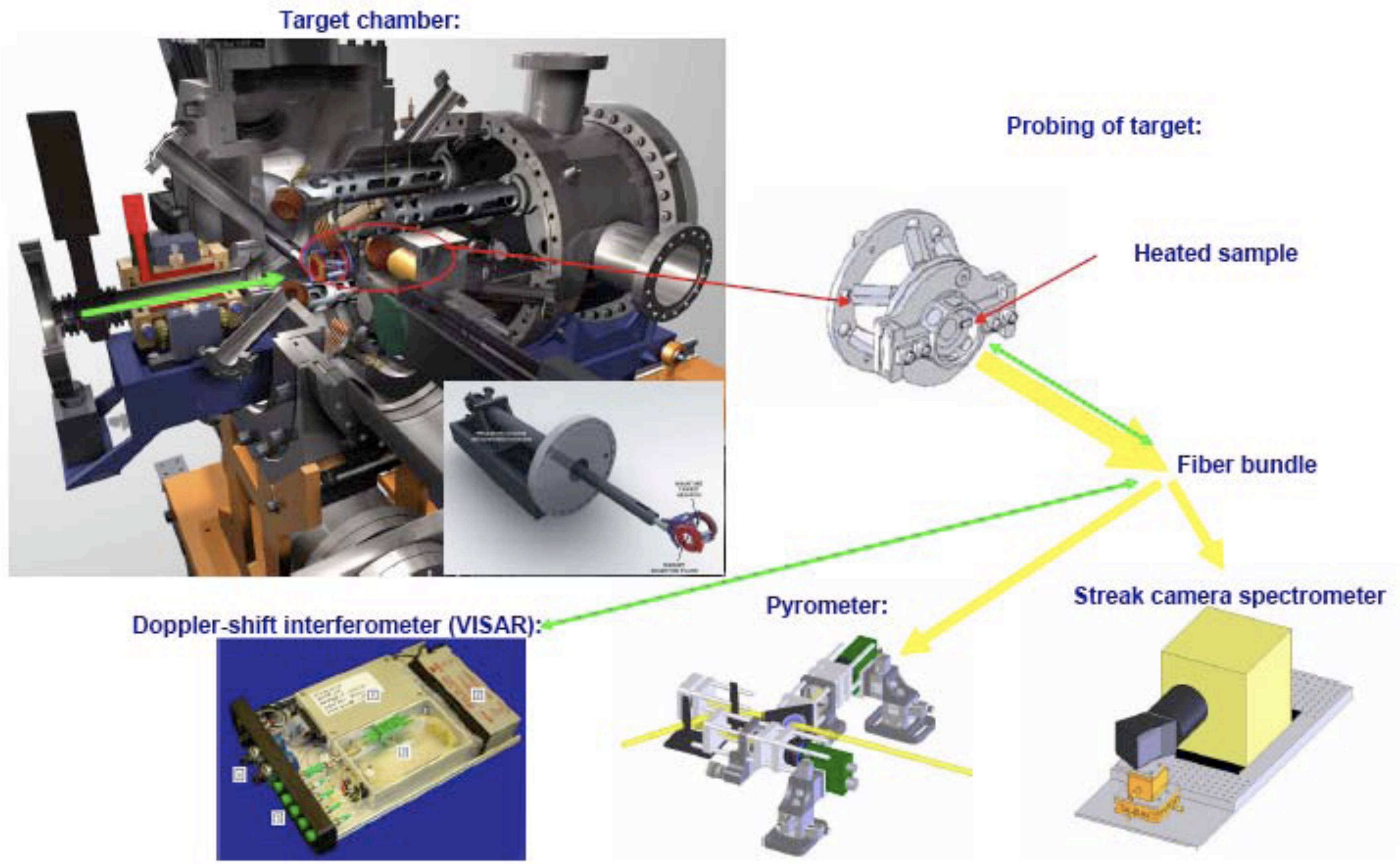


We have identified a series of warm dense matter experiments that can begin on NDCX-I at Temperature < 1 eV

	Target temp.	NDCX-1	NDCX-2
Metallic foam experiments at GSI	~0.5 eV		
Measure target temperature using a beam compressed both radially and longitudinally	Low	√	
Thin target dE/dx, energy distribution, charge state, and scattering in a heated target	Low	√	
Positive - negative halogen ion plasma experiment	>0.4 eV	√	√
Two-phase liquid-vapor metal experiments	0.5-1.0	√	√
Critical point measurements	>1.0	?	√
Ion deposition and coupling experiments	>1.0		√
Collapsing bubble experiments	>1.0		√

time

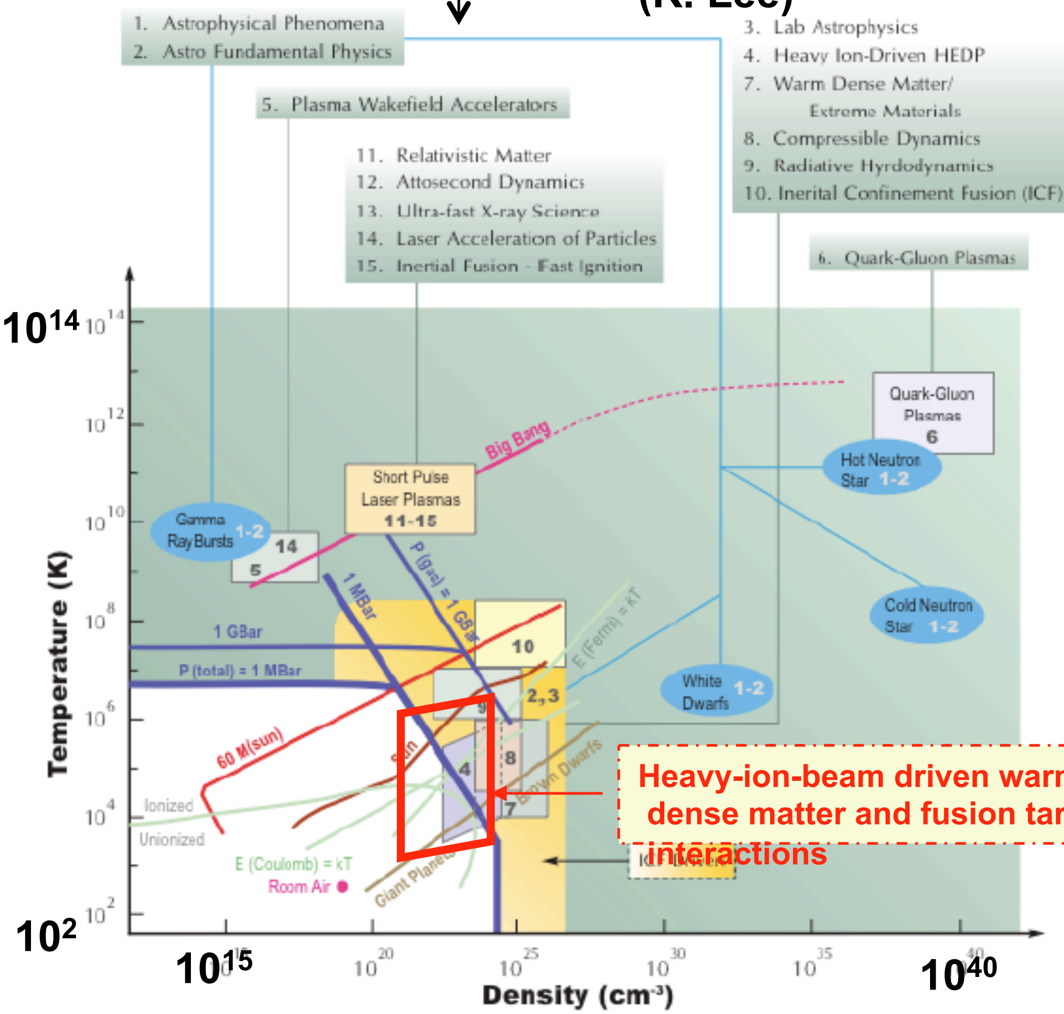
NDCX I now uses a suite of optical diagnostics



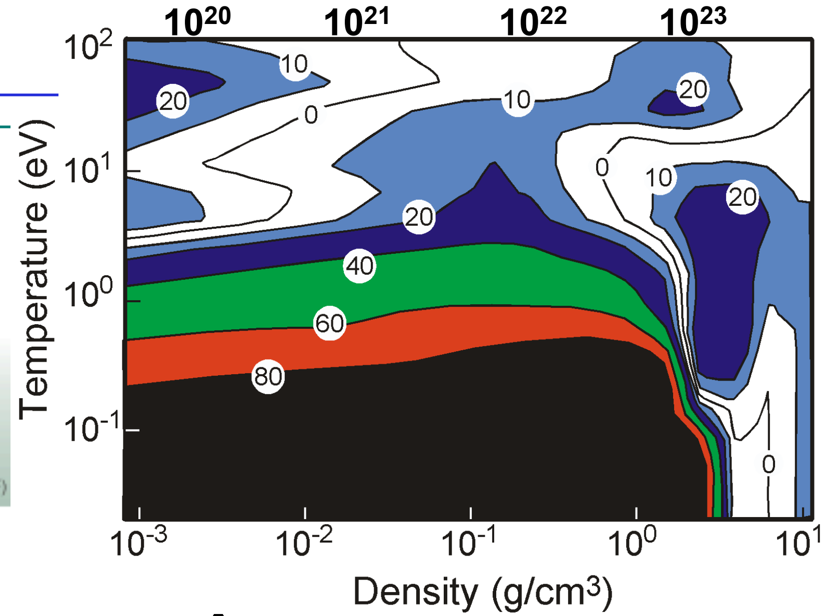
NDCX II covers WDM region -- a region of large uncertainty in EOS

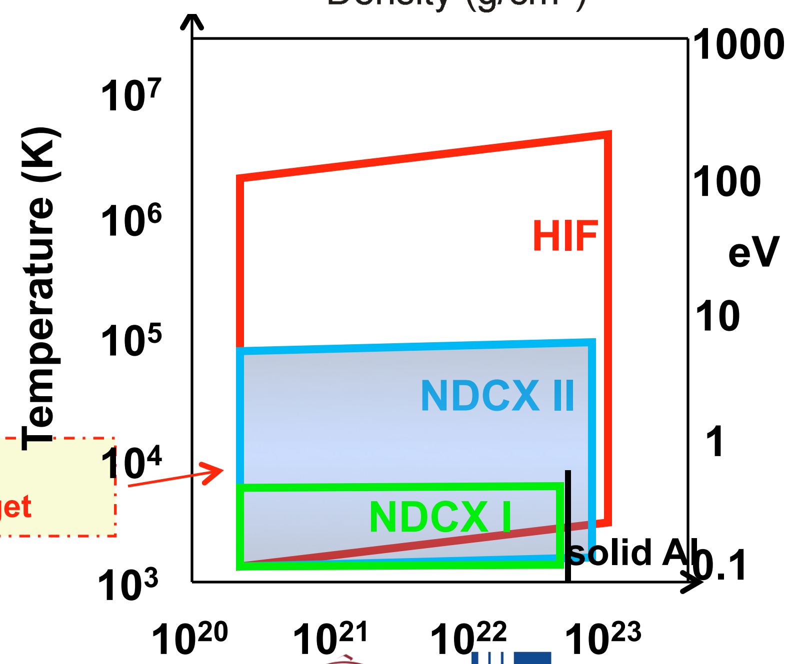
Density - Temperature universe

EOS pressure variance for 2 eqs. of state in Al (R. Lee)

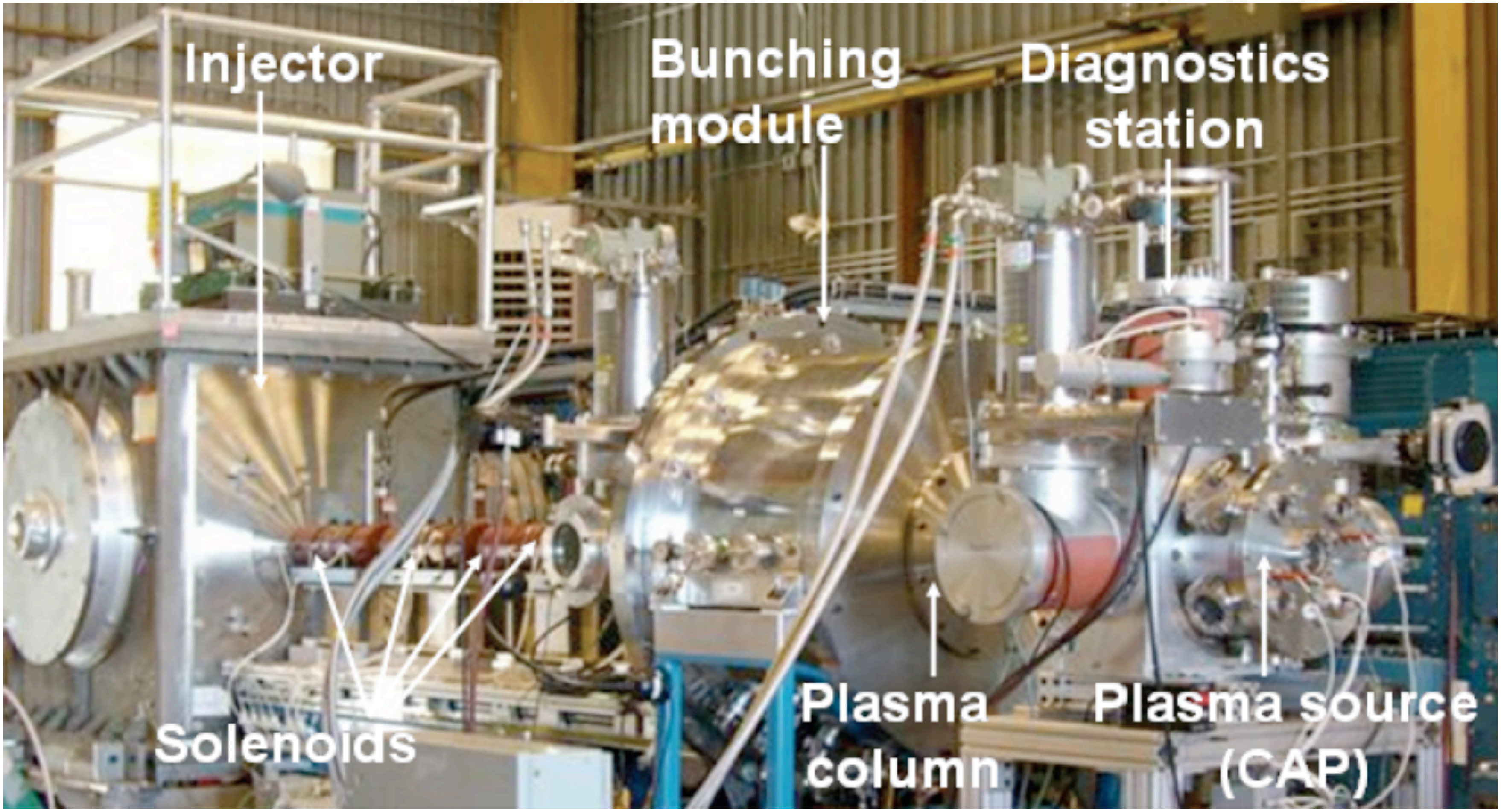


Heavy-ion-beam driven warm dense matter and fusion target interactions





From National HEDP Task Force Report, 2004.


Injector
Bunching module
Diagnostics station
Solenoids
Plasma column
Plasma source (CAP)